CHAPTER 5

Mortality of regenerated *Eucalyptus* species in coastal and inland plantations in KwaZulu-Natal, South Africa

ABSTRACT

The area planted to various species of *Eucalyptus* in KwaZulu-Natal comprises about 52% of the total eucalypt plantation area in South Africa. Eucalypts are predominately grown on a short rotation for pulpwood and sites are continually being regenerated. Although, much research has been done to ensure the survival of seedlings during new inland afforestation, little is known about the incidence of soil invertebrate pests and diseases in low and high productivity coastal and inland regenerated eucalypt sites, and the management thereof. Four trials were planted on previous eucalypt sites, over four growing seasons. Four different site qualities (high productivity inland and coastal sites, low productivity inland and coastal sites) were tested. Seedlings were evaluated monthly after planting, for a period of six months. Stressed, damaged and dead seedlings were uprooted and inspected to determine the cause of death. The highest incidence of soil invertebrate pests (average of 15.16% for both *E. grandis* and *E. dunnii* seedlings) was in the low productivity inland site that was in close proximity to wattle and sugarcane plantations. Whitegrubs and cutworms were the dominant pests and their management would be equivalent to the regeneration of wattle sites. There was a negligible incidence of soil invertebrate pests in the low productivity inland site (average of 0.75% for both *E. grandis* and *E. macarthurii* seedlings), and coastal site (average of 0.25% for all eucalypt species and clones [*E. grandis*, GCSZ11, GU7, GUSZ17, GCSZ14]). Although the high productivity coastal site had a similar low incidence of soil invertebrate pests (average of 2.57% for all eucalypt species and clones [*E. grandis*, GC747, GU170, TAG53, ZG40]), the incidence of whitegrub damage was sporadically high (7.85%) in clone ZG40. Numerous nursery fungal pathogens, the bacterial wilt (*Ralstonia solanacearum*) and unknown factors were responsible for a high loss of establishment of seedlings in the high productivity coastal site. Improving nursery management and screening new clones for pathogen resistance can reduce much of this mortality. The prophylactic application of a pesticide at planting when susceptible species are grown appeared to offer a temporary solution but their routine use is a contravention of the Forest Stewardship Council guidelines.

Keywords: site productivity, seedling mortality, soil invertebrate pests, pathogens, eucalypts

INTRODUCTION

Commercial eucalypt plantations in KwaZulu-Natal consist of 154 940 hectares (ha) of *Eucalyptus grandis* and 108 125 ha of various other eucalypt species, with an annual expansion over the past 20 years of 0.2% and 11.5%, respectively. Together, these plantations comprise about 51.98% of the total area (506 122 ha) planted to various species of *Eucalyptus* in South Africa (Department of Water Affairs and Forestry 2001). Despite this expansion, Burley *et al.* (1989) identified an increasing shortage of wood in South Africa and predicted that demand for wood (sawlogs, pulpwood, mining timber, poles [laths, droppers, transmission, telegraph], firewood, charcoal) and wood products would increase by 3.1% per annum for the next 20 years. They further suggested that the increased forest production would have to come from the use of improved genetic material, cultural techniques, and afforestation of low productivity sites. There has also been a concurrent shift to intensive silviculture of plantations (Schönau 1990) because of the increased wood demand. This intensive silviculture approach will also magnify any factors that affect the establishment of eucalypt seedlings, and ultimately the yield. Therefore, there is a critical need to gain an insight into indigenous pests and diseases that affect the regeneration of eucalypt seedlings in different sites.

Previous research on soil invertebrate pests of eucalypts in southern Africa, concentrated on control measures for termites that affected new afforestation of grassland sites (Atkinson 1989; Mitchell 1990; Schönau & Borthwick 1987), the possible effect of nematode damage during the afforestation of coastal sugarcane sites (Atkinson *et al.* 1991), and improvement in the survival of eucalypts in marginal sites (Schönau & Purnell 1987). Atkinson *et al.* (1992) and Mitchell *et al.* (1987) evaluated the susceptibility of various eucalypt species and clones to termite attack. However, many of these studies did not focus on differentiating between mortality caused by various soil invertebrate pests or diseases. Some pests of eucalypts and their control were assessed in a preliminary report (Atkinson *et al.* 1991), and Govender (1993, 1995) and Govender & Atkinson (1993) evaluated soil invertebrate pests that damaged eucalypts in ex-wattle sites and their control.

Silvicultural studies were conducted on the early growth of eucalypts in response to site preparation (Boden 1984). Little *et al.* (1996) evaluated the survival of seedlings in slash managed and burned sites in the coastal areas of KwaZulu-Natal, from a coppice and weed management, planting practice, sand and nutrient movement and fire perspective. Besides the study by Stone *et al.* (1997), there is also a lack of impact assessments and limited knowledge of pests that affect the establishment of intensively managed Australian eucalypt plantations (Ohmart 1990). The extensive damage that these insects cause illustrates the serious threat to South African eucalypt plantations, should these insects be accidentally introduced.

The identity and status of indigenous soil invertebrate pests in eucalypt regeneration in South Africa are also unclear and our limited knowledge of their incidence is exacerbated by the diversity of local climatic conditions and site characteristics. A prerequisite for the development of any plantation health management strategy is the identification of the insect pests and diseases that prevail over a range of local sites, and the high establishment and management cost of eucalypt plantations raises the economic impact of any destructive agents (Stone *et al.* 1997). This paper, therefore, examines the suite of factors causing mortality in a range of regenerated eucalypt species and clones in low and high productivity coastal and inland eucalypt sites in South Africa, so that appropriate control measures may be adopted where necessary. This study is also directed at quantifying the impact of pests and diseases to obtain a cost/benefit analysis of control strategies.

MATERIALS AND METHODS

Four trials were planted on previous eucalypt sites over four growing seasons (1995/96 to 1998/99) to determine the mortality factors affecting the regeneration of eucalypts. Sites were selected in KwaZulu-Natal Province, South Africa. These sites represented low and high productivity coastal and inland regions of the eucalypt production area, where the plantation residue management varied according to the practice of the region. Trial 1 (Pietermaritzburg: 29° 32′ S, 30° 27′ E) was on a low productivity inland site where the plantation residue was windrowed and burnt prior to planting. Trial 2 (Howick: 29° 27′ S, 30° 13′ E) was on a high productivity inland site where the plantation residue was windrowed but not burnt prior to planting. Trial 3 (KwaMbonambi: 28° 36′ S, 32° 06′ E) was on a high productivity site and trial 4 (Nyalazi: 28° 03′ S, 32° 24′ E) was on a low productivity site, and in both these coastal sites the plantation residue was broadcast after harvesting.

Seedlings were evaluated monthly for a period of six months after planting. Stressed, damaged and dead seedlings were dug together with approximately 0.012 m^3 of the surrounding soil to determine the cause of death. Mortality was determined according to the symptomatic damage caused by the various soil invertebrate pests and this was confirmed in many instances by the presence of the pest. Mortality was expressed as a percentage loss of establishment, where damage by soil invertebrate pests is equivalent to percentage infestation. Trials 1 and 2 were a randomised complete block design of five tree species (plots) per replicate (total four) with 100 seedlings/plot. However, only two of the five tree species in each trial were *Eucalyptus* (*E. grandis* and *E. dunnii* [trial 1], *E. grandis* and *E. macarthurii* [trial 2]). Large trials with many trees per plot were planted because of the aggregate nature of soil invertebrate distributions (Allsopp & Bull 1989; Edwards 1991).

Besides soil invertebrate pest infestations, other mortality factors, especially pathogens were also evaluated in the two coastal trials where pathogens were reported as a problem of establishment. It was not possible to determine the incidence of pathogens with the symptomatic or pathogen isolation approach because most seedlings dried out during the monthly survey interval and the isolation for pathogens only showed saprophytes. Hence, an empirical methodology with an insecticide (chlordane 60% EC), fungicide (benomyl 50% WP) and a mixture of this insecticide and fungicide were used. Trials 3 and 4 were a 5 plot x 5 plot latin square design with five *Eucalyptus* species plots and 120 seedlings/plot. Each plot was divided into five sub-plots of 24 seedlings. Each sub-plot was randomly treated with either an insecticide, or a fungicide, or a mixture of both, and two sub-plots were untreated. The responses to these treatments compared to untreated plots was used to determine whether soil insect pests or pathogens were responsible for seedling mortality in instances where a diagnosis could not be made (seedling or pest absent, damage symptoms similar to other mortality factors or dry seedlings). The *Eucalyptus* species and clonal cuttings tested were the plantation species considered most suitable for the particular trial site, and included *E. grandis* seedlings (both trials) and clones GC747, TAG53, GU170, ZG40 (trial 3), and GCSZ11, GU7, GUSZ17, GCSZ14 (trial 4).

An analysis of variance (ANOVA) was carried out using Genstat for Windows^{TM} (Lane & Payne 1996) to test for statistically significant differences (Mead & Curnow 1983) within each of the trials. Additional ANOVA was undertaken for each of the mortality factors and surviving trees of each tree species in trials 3 and 4. Where statistically significant differences were detected, non-significant subsets were derived by Least Significant Differences (LSD's). These analyses allowed the testing of the validity of the symptomatic damage approach in order to adjust the recorded incidence of pests and diseases from other mortality factors when significant responses to pesticides were observed.

A pest database of extension visits and reported incidences of seedling damage (Pest & Diseases DataBase) was initiated at the start of these experiments. This was used to supplement the evaluation of the status of soil invertebrate pests and diseases and to justify the inclusion of a table on pests and diseases that were not observed in the trial series.

RESULTS AND DISCUSSION

Low productivity inland site

The highest failure of *E. grandis* and *E. dunnii* seedlings to establish (average of 21.40% across both species) and the highest incidence of soil invertebrate pests (average of 15.16% across both species) was observed in the low productivity inland site (Table 1). Soil invertebrate pests, especially whitegrubs and cutworms caused about 66% and 75% of the total mortality of *E. dunnii* and *E. grandis* seedlings, respectively. This was the second rotation of eucalypts on this site, which was previously planted to wattle. It has been shown that whitegrubs and cutworms are dominant soil invertebrate pests of wattle stands, where the plantation residue was windrowed and burnt (Chapter 3). The close proximity of this site to sugarcane and wattle and its previous wattle land-use may account for the high status and numbers of these pests. There was a highly significant increase in the incidence of whitegrub damage on the *E. grandis* (12.34%) than the *E. dunnii* seedlings (6.04%) (ANOVA: $F_{4,57}$ = 12.17, $P < 0.01$), and of cutworm damage on the *E. dunnii* (6.50%) than the *E. grandis* seedlings (3.38%) (ANOVA: $F_{4,57} = 47.20$, $P < 0.01$). The combined incidence of these pests on *E. dunnii* (12.54%) and *E. grandis* seedlings (15.72%) was, however similar. Since the *E. dunnii* seedlings were tender and younger than the older *E. grandis* seedlings, this led to their greater susceptibility to cutworm attack, which occurred shortly after planting. One would expect that if cutworms did not first attack these seedlings, they would have succumbed and there would have been an increased incidence of whitegrub damage. The low incidence of termite, tipulid larvae and millipede damage was similar to that observed in the regeneration of wattle (Chapter 3). Although a low incidence of termite damage on this regenerated eucalypt site was expected, it is interesting to note that only the *E. dunnii* seedlings, which are supposed to be the most tolerant to termite attack (Atkinson *et al.* 1992), were damaged (0.75%) and not the 'very susceptible' *E. grandis* seedlings.

High productivity inland site

In contrast, the high productivity inland site had few seedlings of *E. grandis* and *E. macarthurii* that failed to establish (average of 4.89% across both species), and there was a very low incidence of soil invertebrate pests (average of 0.75% across both species) (Table 1). Cutworms were the more important of the sporadic soil invertebrate pests and the decreased incidence of cutworm damage was because the eucalypt seedlings that were planted were older than usual and had thicker stems. This indication that cutworms have a higher status than other soil invertebrate pests was consistent with extension reports of high incidences of cutworm damage during the regeneration of high productivity eucalypt sites, especially when the plantation residue was burnt (Pest & Diseases DataBase). The very low presence of whitegrub larvae and hence damage is probably because indigenous chafer beetles neither associate nor defoliate eucalypt trees in South Africa (Swain & Prinsloo 1986), unlike the situation in Australia where adult scarab beetles seriously defoliate newly planted and established eucalypts (Ohmart 1990). There was a slightly increased but low incidence of nursery related pathogens compared to the low productivity inland site. Older seedlings face a greater the risk of pathogen infestation, when held in the nursery for longer than necessary, but can be easily controlled by using the correct nursery practices (Nichol 1992). Many common nursery pathogens often manifest in the filed after planting.

Table 1: Percent loss of *Eucalyptus* seedling establishment in coastal and inland regeneration in KwaZulu-Natal, South Africa. (HPS: high productivity site, LPS: low productivity site) (values in bold have been adjusted following ANOVA)

MORTALITY FACTOR	COASTAL (HPS)					COASTAL (LPS)					INLAND (LPS)		INLAND (HPS)	
	GC747	*E.grandis*	TAG53	GU170	ZG40	GCSZ11	*E.grandis*	GU7	GUSZ17	GCSZ14	*E.dunnii*	*E.grandis*	*E.mac*	*E.grandis*
whitegrubs	0.00	1.04	1.25	1.04	1.25	0.00	0.00	0.42	0.00	0.00	6.04	12.34	0.25	0.00
cutworms	0.00	0.42	0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.50	3.38	0.00	1.00
termites	0.00	0.00	0.00	0.00	0.00	0.42	0.00	0.00	0.00	0.00	0.75	0.00	0.00	0.00
tipulids	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.00
millipedes	0.00	0.00	0.00	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.63	0.42	0.00	0.00
nematodes	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
wireworms	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
crickets	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
grasshoppers	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00
ants	0.00	0.00	0.21	0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
unknown pests	0.00	0.00	0.00	0.00	**6.60**	**0.40**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SOIL INVERT. PEST LOSS	*0.00*	*1.46*	*1.88*	*1.67*	*7.85*	*0.82*	*0.00*	*0.42*	*0.00*	*0.00*	*13.92*	*16.39*	*0.50*	*1.00*
browsing	0.00	0.00	0.00	0.00	0.42	0.00	0.00	0.00	0.00	0.00	0.88	0.00	0.00	0.00
pathogens	**0.12**	**0.99**	**9.59**	**0.33**	**6.73**	**0.49**	**0.01**	**0.05**	**0.03**	**0.05**	0.13	0.25	1.00	2.38
bacterial wilt	2.92	3.75	**0.49**	9.17	5.42	0.42	1.67	0.00	0.83	0.42	0.00	0.00	0.00	0.00
weed related	0.00	0.00	0.00	0.00	0.00	0.42	0.42	0.83	0.00	0.00	2.75	2.75	0.00	2.00
planting related	0.00	0.42	0.42	0.00	0.00	0.00	0.00	0.00	0.42	0.00	2.46	1.50	1.13	0.38
nursery related	0.00	**0.05**	0.00	0.63	0.42	0.63	0.63	0.55	0.97	0.63	0.00	0.63	0.88	0.00
abiotic	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.42	0.88	0.00	0.00	0.00
unknown	**2.80**	0.42	**6.79**	**7.80**	1.25	**1.79**	**1.03**	**1.06**	**1.50**	**1.82**	0.00	0.25	0.25	0.25
theft	2.50	2.92	2.08	0.83	1.25	**0.03**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL LOSS	*8.34*	*10.01*	*21.25*	*20.43*	*23.34*	*4.60*	*3.76*	*2.91*	*3.75*	*3.34*	*21.02*	*21.77*	*3.76*	*6.01*

Low productivity coastal site

In the low productivity coastal site, few seedlings failed to establish (average of 3.67% across all species) and there was a negligible incidence of soil invertebrate pests (average of 0.25% across all species) (Table 1). This was a second rotation eucalypt site, where low incidences of whitegrub, termite and unknown insect damage was recorded. Each of the mortality factors was assessed for responses to the pesticide treatments using ANOVA. In instances where there were statistically significant responses, this mortality was adjusted and to an unknown soil invertebrate pest category (responses to insecticide treatment) or pathogen category (responses to fungicide treatment) or unknown category where there was no response. Although there was a regular but low incidence of suspected nursery pathogens present in all the eucalypt species planted, this mortality factor failed to show a response to the fungicide treatments, and was transferred to the unknown mortality category. The lack of any statistically significant soil invertebrate pest or pathogen infestations was verified by a non-significant response of all surviving trees (ANOVA: $F_{16,80} = 0.67$, $P = 0.82$) to the different pesticide treatments (Table 2). An unconfirmed but low incidence of bacterial wilt (*Ralstonia solanacearum*) was discovered in the coastal eucalypt region during the duration of the trial (Coutinho *et al.* 2000). *Eucalyptus grandis* seedlings showed a highly statistically significant greater susceptibility (1.67% mortality) to bacterial wilt compared to the other clones (ANOVA: $F_{4,12} = 8.12$, $P < 0.01$). Currently, all new clones are screened for pathogen resistance before large-scale production and field deployment (Conradie *et al.* 1992, Roux *et al.* 1999, Smith *et al.* 2002, Wingfield *et al.* 2001, Van Heerden 1999), and these results with bacterial wilt support such an approach. Overall though, there was no difference in survival of untreated seedlings between the various eucalypt species (ANOVA: $F_{4,12} = 0.80$, $P = 0.55$) because of the low incidence of the various mortality factors.

Table 2: Interaction of pesticide treatments in surviving *Eucalyptus* seedlings in the coastal trial sites (KwaZulu-Natal, South Africa).

PESTICIDE TREATMENT versus CONTROL	Analysis of variance: difference of means									
	High productivity site LSD: 5% (0.1648), 1% (0.2191)					Low productivity site LSD: 5% (0.2023), 1% (0.2691)				
	GC747	*E.grandis*	TAG53	GU170	ZG40	GCSZ11	*E.grandis*	GU7	GUSZ17	GCSZ14
Insecticide	0.080	0.032	0.087	0.113	0.241**	0.111	0.093	0.029	0.036	0.097
Fungicide	0.040	0.006	0.228**	0.047	0.264**	0.014	0.066	0.113	0.089	0.000
Mixture	0.239**	0.168*	0.244**	0.194*	0.407**	0.071	0.023	0.005	0.070	0.140

High productivity coastal site

In the high productivity coastal site, a high failure of seedlings to establish was recorded in all *Eucalyptus* species and clones (ZG40 [23.34%], GU170 [20.34%], TAG53 [21.25%], *E. grandis* seedlings [10.01%], GC747 [8.34%]) (Table 1). There was no soil invertebrate pest damage in clone GC747, a low incidence of soil invertebrate pest damage in *E. grandis* (1.46%), TAG53 (1.88%) and GU170 (1.67%) seedlings but a high incidence of soil invertebrate pest damage in ZG40 (7.85%) seedlings. On average, across all eucalypt species in this trial, whitegrubs were the dominant soil invertebrate pests (0.92%), followed by cutworms (0.17%), ants (0.13%) and millipedes (0.04%). The incidence of soil invertebrate pests in clone ZG40 was adjusted to include an unknown pest category following statistically significant responses to the insecticide treatments in the pathogen mortality factor category (Table 1). There was a highly statistically significant difference in survival between insecticide treated and untreated ZG40 seedlings because of the observed whitegrub damage (ANOVA: $F_{4,80} = 6.60$, $P < 0.001$). Hence, the high incidence of unknown pests in ZG40 seedlings was probably a late attack by whitegrubs that were undetected in earlier surveys. Although ants were recorded as a soil invertebrate pest, they did not directly damage the seedlings but mined the soil from the planting pit, which created air pockets that desiccated the seedling roots. Although grasshopper damage was not recorded on the untreated seedlings (Table 1), it was observed on pesticide treated seedlings. Across all eucalypt species in this trial, soil invertebrate pests were generally responsible for an average of 13.05% of the total mortality recorded, suggesting that soil invertebrate pests are not as important as some of the other mortality factors. This was verified by a lack of a response to the insecticide treatments in most surviving eucalypt species, except clone ZG40 (Table2).

Besides the unknown mortality category, the incidence of pathogens (average of 3.55%) and bacterial wilt (average of 4.35%) damage were responsible for an average 45.96% of the total mortality across all species of eucalypts (Table 1). The incidence of recorded pathogen damage, which was initially highest in clone ZG40, showed highly statistically significant responses to fungicide treatments (ANOVA: $F_{16,80} = 2.28$, P < 0.01) (Table 2). Nursery related mortality in *E. grandis* seedlings showed statistically significant responses to fungicide treatments, and was adjusted to the pathogen mortality category. This demonstrates that many nursery pathogens manifest in the field after planting. Mortality of TAG53 seedlings that were previously attributed to bacterial wilt, showed statistically significant responses to the fungicide treatment (Table 2), and were consequently adjusted to the pathogen category (ANOVA: $F_{4,80}$ = 4.49, $P < 0.01$). However, similar to the low productivity coastal site, the diagnosis of bacterial wilt was unconfirmed. Despite the low incidence of soil invertebrate pests and pathogens in some eucalypt clones, there was a statistically significant improvement in the survival of all species of eucalypts (ANOVA: $F_{4,80}$ = 11.55, $P < 0.001$) when a combined insecticide and fungicide treatment was applied (Table 2).

A comparison of the survival of the various species of eucalypt seedlings indicated that although there were no statistically significant differences between clone GC747 and *E. grandis* seedlings, they were highly significantly better than clones GU170, TAG53 and ZG40 (ANOVA: $F_{4,12}$ = 5.82, $P < 0.01$). There were no significant differences in survival between the latter three clones. Stone *et al.* (1997) observed that it was not until the second season after planting that insects or fungi significantly attacked trees. However, in South Africa, soil invertebrate pests cause primary damage soon after planting but the incidences of fungal pathogen damage are often stress-related and may occur later in the rotation (Conradie *et al.* 1992, Wingfield *et al.* 2001). Consequently, all comparisons of eucalypt seedling survival can change with respect to pathogen susceptibility.

Other eucalypt establishment pests

Several other pests that were recorded over a fourteen-year period from extension visits and samples submitted for diagnosis or identification (Pest & Diseases Database), affect the establishment of eucalypt seedlings, but were not encountered in this study. A list of those pests affecting eucalypt seedlings, the most commonly recorded hosts, and a brief commentary of occurrence and damage are presented in Table 3.

Abbott (1993), Bashford (1993), Neumann (1993), Phillips (1993), Stone (1993), and Wylie and Peters (1993) reviewed the native insect pests of eucalypt plantations across all states of Australia, and the economically important damage groups were defoliators, sap-suckers and wood-borers. Only in South and Western Australian plantations were there records of soil invertebrate pests [grasshoppers (*Phaulacridium vittatum* Sjostedt), adult scarabaeid beetles (*Heteronychus arator* Fabr.), cutworms (*Agrotis* sp.)] (Phillips 1993; Abbott 1993), that were similar to that causing damage to eucalypt seedlings in South Africa.

Table 3. List of damaging invertebrate, animal agents and pathogens and their main hosts during eucalypt establishment in southern Africa. Extracted from Pest & Diseases Database of extension reports.

Scientific name	Common name	Most commonly recorded hosts	Comments
ORTHOPTERA			
Macrogryllus spp. [Gryllidae]	giant crickets	GU7	occasional damage to seedlings in coastal areas
Brachytrypes membranaceus Drury [Gryllidae]	giant crickets	GC121	occasional damage to seedlings in coastal areas
Zonoceres elegans (Thunberg) [Pyrgomorphidae]	elegant grasshopper	*E. grandis*	occasional defoliation of seedlings on burnt sites
COLEOPTERA			
Colasposoma femorale Lefevre [Chrysomelidae]	green & bronze	*E. grandis*	defoliation of seedlings
Colasposoma pusillum Jacoby [Chrysomelidae]	green & bronze	*E. mac*	defoliation of seedlings
Colasposoma semihirsutum Jacoby [Chrysomelidae]	green & bronze	*E. mac*	defoliation of seedlings
Hypopholis sommeri Burmeister [Scarabaeidae]	whitegrub larvae	*E. grandis*	severe damage as root feeders
Asthenopholis subfasciata Blanchard [Scarabaeidae]	whitegrub larvae	*E. grandis*	severe damage as root feeders
Schizonycha fimbriata Brenske [Scarabaeidae]	whitegrub larvae	*E. dunnii, E. grandis* GxN	severe damage as root feeders
Monochelus calcaratus Burmeister [Scarabaeidae]	chafer	*E. dunnii*	defoliation of seedlings
Heteronychus arator Fabricius [Scarabaeidae]	black maize beetle	*E. dunnii, E. nitens*	adults strip bark off seedlings, ex-maize lands
Protostrophus sulcatifrons (Marshall) [Curculionidae]	ground weevil	*E. nitens, E. mac*	occasional complete defoliation of stem & leaves
Protostrophus salignae Marshall [Curculionidae]	ground weevil	*E. grandis, E. grandis* panbult	occasional complete defoliation of stem & leaves
Protostrophus noxius Marshall [Curculionidae]	ground weevil	*E. camaldulensis*	occasional complete defoliation of stem & leaves
Gonipterus scutellatus Gyllenhal [Curculionidae]	eucalypt snout beetle	*E. dunnii, E. grandis* GC522, GC clones	severe defoliation of young seedlings
Ellimenistes laesicollis Fahraeus [Curculionidae]	ellimenistes	*E. grandis*, TAG5 TAG28, *E. mac*, GC5	stem abrasion and snapping
Gonocephalum spp. [Tenebrionidae]	ground beetles	*E. grandis*	adults damage seedling stems
LEPIDOPTERA			
Agrotis spp. [Noctuidae]	cutworms	*E. grandis, E. dunnii* TAG53, *E. mac*	sporadic damage to young seedlings severs stem at ground level
HEMIPTERA			
Ctenarytaina eucalypti Maskell [Psyllidae]	psyllids	*E. dunnii, E. nitens* *E. globulus*	occasional sap sucker
Tuberolachnus salignus Gmelin. [Aphididae]	giant aphid	*E. fastigata*	occasional sap sucker
ISOPTERA			
Hodotermes mossambicus (Hagen) [Hodotermitidae]	termites	coastal clones	occasional root and bark feeder
Macrotermes natalensis Haviland [Termitidae]	termites	GC341, *E. nitens*, *E. saligna*, *E. grandis* *E. dunnii*, GxN	root and bark feeder - extensive during new afforestation
RODENTIA			
Otomys irroratus Brants	vlei rat	*E. nitens, E. fas*	during afforestation of grassland areas
PATHOGENS			
Sporothrix eucalypti			leaf pathogen on cuttings
Phytopthora cinnamomi	root rot	*E. mac, E. smithii*	nursery seedlings and infield mortality
Cylindrocladium sp.		*E. grandis*	nursery seedlings and infield mortality
Pythium sp.		*E. mac*	nursery seedlings and infield mortality
Botrytis sp.		*E. nitens*, nos. clones	nursery seedlings and infield mortality
Pantoea ananatis		*E. smithii, E. grandis*	nursery seedlings and infield mortality
Colletotrichum gloeosporioides		*E. nitens*, nos. clones	nursery seedlings and infield mortality

Site productivity and management considerations

Inland low and high productivity eucalypt sites showed large differences in the percentage of seedlings that failed to establish. However, these differences were expressed in the magnitude of the mortality factors and not the suite of factors causing mortality. Failure of eucalypt seedlings to establish was negligible in the high productivity site compared to the low productivity site, where soil invertebrate pests were the dominant causes of mortality. These soil invertebrate pests were similar to the pests affecting the regeneration of wattle seedlings (Chapter 3), and the incidence of whitegrub and cutworm damage was economically important. The expansion of eucalypt plantations has been and would be into previous sugarcane or wattle plantations and the management of the establishment of these plantations should be similar to that for wattle regeneration. If new afforestation is into previous grasslands an increased incidence of termite damage can be expected (Atkinson *et al.* 1992). These high incidences of soil invertebrate pests, supports the case for the prophylactic application of insecticides at planting in the limited number of high-risk, low productivity inland eucalypt sites, whereas in high productivity inland eucalypt sites, the corrective application of insecticides will suffice. This site-specific silvicultural management represents an improvement of the current recommendations by Atkinson (1989, 1997) that insecticides should generally be applied preventatively at planting as an insurance against pest attack. Such an approach contravenes the Forest Stewardship Council (FSC) guidelines (Govender 2002) and increases the possibility of insecticide resistance development. Pesticide application is a short-term option due to the costs involved with the necessary monitoring, chemical applications and associated environmental issues (Stone *et al.* 1997). An assessment of the FSC guidelines governing the use of insecticides (Govender 2002), and an investigation into alternative control measures (microbial insecticides, parasitic nematodes) is therefore warranted.

The coastal eucalypt sites had a negligible incidence of soil invertebrate pests (except for clone ZG40 in the high productivity site) but a high incidence of fungal and bacterial pathogens. Although the identity of the fungal pathogens was not determined, it is suspected that they were nursery pathogens that manifested in the field after planting. Numerous nursery pathogens (*Phytopthora cinnaamomi*, *Pythium* spp., *Colletotrichum* spp., *Pestalopsis* spp., *Botrytis* spp., *Alternaria* spp., *Cylindrocladium* spp.) were previously isolated from diseased seedlings submitted for diagnosis (Pest & Diseases Database). Together with bacterial wilt, pathogens are the dominant cause of seedling mortality in the coastal eucalypt sites. Although it is possible to treat seedlings with fungicides, similar constraints as with the use of insecticides above, apply. It would probably be economically viable to preventatively treat seedlings in the production and holding nurseries rather than at planting, and to select resistant species like GC747 for planting. However, the use of insecticides and fungicides at planting, would boost the survival of species that are not the first choice for that site but that have desirable pulp properties.

ACKNOWLEDGEMENTS

I thank the Institute for Commercial Forestry Research, South Africa, and its patron forestry companies for funding and supporting this research. I am particularly grateful to the many forestry personnel and field staff of SAWGU, SAPPI, MONDI and SAFCOL, who assisted in planting and maintaining the various trials. I also thank Prof. Clarke Scholtz for reviewing the manuscript, and Prof. G. P. Y. Clarke (University of Natal, Pietermaritzburg), for statistical assistance.

REFERENCES

Abbott, I. 1993. Insect pest problems of eucalypt plantations in Australia 6. Western Australia. *Australian Forestry* **56:** 381-384.

Allsopp, P. G. & Bull, R. M. 1989. Spatial patterns and sequential sampling plans for melolonthine larvae (Coleoptera: Scarabaeidae) in southern Queensland sugarcane. *Bulletin of Entomological Research* **79:** 251-258.

Atkinson, P. R. 1989. Controlled-release insecticide granules, compared with other soil insecticides, for use against the termite, *Macrotermes natalensis* Haviland in the establishment of *Eucalyptus* plantations. *Crop Protection* **8:** 387-396.

Atkinson, P. R. 1997. Recommendations, practices and notes on the control of pests and diseases in commercial forestry in South Africa. *ICFR Bulletin Series* **1/97**. Institute for Commercial Forestry Research, University of Natal, Pietermaritzburg.

Atkinson, P. R., Nixon, K. M. & Shaw, M. J. P. 1992. On the susceptibility of *Eucalyptus* species and clones to attack by *Macrotermes natalensis* Haviland (Isoptera: Termitidae). *Forest Ecology and Management* **48:** 15-30.

Atkinson, P. R., Tribe, G. D. & Govender, P. 1991. Pests of importance in the recent expansion of *Eucalyptus* plantings in South Africa. In: *Intensive Forestry: The role of Eucalypts*. (ed. A. P. G. Schönau). Proceedings of IUFRO Symposium, Durban, South Africa, Volume **2:** 728-738.

Atkinson, P. R., Van den Berg, E. & Van Rensburg. 1991. Response of *Eucalyptus* to aldicarb in coastal sandy soils in Natal, South Africa. *South African Forestry Journal* **158:** 5-9.

Bashford, R. 1993. Insect pest problems of eucalypt plantations in Australia 4. Tasmania. *Australian Forestry* **56:** 375-377.

Boden, D. I. 1984. Early responses to different methods of site preparation for three commercial tree species. In: *Site and productivity of fast growing plantations.* (Eds. D. C. Grey, A. P. G. Schönau, C. J. Schutz and A. van Laar). Proceedings of IUFRO Symposium, Pretoria and Pietermaritzburg, South Africa, 30 April-11 May 1984, Volume **2:** 565-578.

Burley, J., Armitage, F. B., Barnes, R. D., Gibson, G. L., Hardcastle, P. D., Huguet, L., Plumptre, R. A. & Wood, P. J. 1989. Forestry research in eastern and southern Africa. *Tropical Forestry Papers No.* **19**. Oxford Forestry Institute, London.

Conradie, E., Swart, W. J. & Wingfield, M. J. 1992. Susceptibility of *Eucalyptus grandis* to *Cryphonectria cubensis*. *European Journal of Forest Pathology* **22:** 312-315.

Coutinho, T. A., Roux, J., Riedel, K-H., Terblanche, J. & Wingfield, M. J. 2000. First report of bacterial wilt caused by *Ralstonia solanacearum* on eucalypts in South Africa. *Forest Pathology* **30:** 205-210.

Department of Water Affairs and Forestry. 1980 - 2001. Report on commercial timber resources and roundwood processing in South Africa. **1980-2001**. Pretoria.

Edwards, C. A. 1991. The assessment of populations of soil-inhabiting invertebrates. *Agriculture, Ecosystems and Environment* **34:** 145-176.

Govender, P. 1993. Pests of establishment of eucalypts and wattle. In: *ICFR Annual Research Report*, pp. 161-170. Institute for Commercial Forestry Research, University of Natal, Pietermaritzburg.

Govender, P. 1995. The pest status and chemical control of whitegrubs and cutworms in forestry in the Natal Midlands. *MSc thesis*. University of Natal, Pietermaritzburg.

Govender, P. 2002. Management of insect pests: Have the goalposts changed with certification? *Southern African Forestry Journal* **195:** 39-45.

Govender, P. & Atkinson, P. R. 1993. The soil pest complex and its control in the establishment of commercial eucalypt and wattle plantations in South Africa. *ICFR Bulletin Series* **18/93**. Institute for Commercial Forestry Research, University of Natal, Pietermaritzburg.

Lane, P. W. & Payne, R. W. 1996. *Genstat, for Windows^{TM} an introductory course*. The Numerical Algoriths Group Limited, United Kingdom.

Little, K., Eccles, N., Oscroft, D., Viero, P. & Eastwood, T. 1996. Growth of eucalypts on slash managed and burned sites in Zululand. *ICFR Bulletin Series* **3/96**. Institute for Commercial Forestry Research, University of Natal, Pietermaritzburg.

Mead, R. & Curnow, R. N. 1983. *Statistical methods in agriculture and experimental biology*. Chapman and Hall, London.

Mitchell, M. R. 1990. Comparison of non-persistent insecticides in controlled release granules with a persistent organochlorine insecticide for the control of termites in young *Eucalyptus* plantations in Zimbabwe. *Commonwealth Forestry Review* **68:** 281-294.

Mitchell, M. R., Gwaze, D. P. & Stewart, H. T. L. 1987. Survival and early growth of Australian tree species planted at a termite infested site in Zimbabwe. *East African Forestry Journal* **52:** 251-259.

Neumann, F. G. 1993. Insect pest problems of eucalypt plantations in Australia 3. Victoria. *Australian Forestry* **56:** 370-374.

Nichol, N. 1992. Plantation Pathology: Notes for identification of common pathological problems in South African forestry. *ICFR Bulletin Series* **23/92**. Institute for Commercial Forestry Research, University of Natal, Pietermaritzburg.

Ohmart, C. P. 1990. Insect pests in intensively-managed eucalypt plantations in Australia: Some thoughts on this challenge to a new era in forest management. *Australian Forestry* **53:** 7-12.

Pest & Diseases DataBase. 2002. Forestry and Agricultural Biotechnology Institute. University of Pretoria, Pretoria. South Africa.

Phillips, C. L. 1993. Insect pest problems of eucalypt plantations in Australia 5. South Australia. *Australian Forestry* **56:** 378-380.

Roux, J., Wingfield, M. J. & Dunlop, R. 1999. Susceptibility of elite *Acacia mearnsii* families to *Ceratocystis* wilt in South Africa. *Journal of Forest Research* **4:** 187-190.

Schönau, A. P. G. 1990. Role of eucalypt plantations in timber supply and forest conservation in sub-saharan Africa. Proceedings of 19th IUFRO World Congress, Montreal, Canada, Division 2: 311-319.

Schönau, A. P. G. & Borthwick, R. B. 1982. Insect pests of *Eucalyptus* spp.: chemical control of termites. In: *WRI Annual Research Report*, pp. 77-78. Wattle Research Institute, University of Natal, Pietermaritzburg.

Schönau, A. P. G. & Purnell, R. C. 1987. A different approach to site evaluation and some preliminary results. *South African Forestry Journal* **141:** 19-25.

Smith, H., Coutinho, T. A., Wolfaardt, F. W. & Wingfield, M. J. 2002. Relative susceptibility of northern and southern provenances of *Pinus gregii* to infection by *Sphaeropsis sapinea*. *Forest Ecology and Management* **166:** 331-336.

Stone, C. 1993. Insect pest problems of eucalypt plantations in Australia 2. New South Wales. *Australian Forestry* **56:** 363-369.

Stone, C., Simpson, J. A. & Eldridge, R. H. 1997. Insect and fungal damage to young eucalypt trial plantings in northern New South Wales. *Australian Forestry* **61:** 7-20.

Swain, V. M. & Prinsloo, G. L. 1986. A list of the phytophagous insects and mites on forest trees and shrubs in South Africa. *Entomology Memoir* **66:** 1-91.

Van Heerden, S. W. 1999. Population biology and hypovirulence in *Cryphonectria cubensis* in South Africa. *MSc thesis*. University of Pretoria, Pretoria, South Africa.

Wingfield, M. J., Roux, J., Coutinho, T. A., Govender, P. & Wingfield, B. D. 2001. Plantation disease and pest management in the next century. *Southern African Forestry Journal* **190:** 67-71.

Wylie, F. R. & Peters, B. C. 1993. Insect pest problems of eucalypt plantations in Australia 1. Queensland. *Australian Forestry* **56:** 358-362.

CHAPTER 6

Effects of plantation residue management and mortality on *Pinus* regeneration in South Africa

ABSTRACT

The area planted to various species of *Pinus* comprises about 53% of the total commercial plantation area in South Africa. The cyclic nature of plantation forestry results in areas being continually regenerated to pines and considerable silvicultural research has been done to ensure the survival of seedlings during regeneration. Soil invertebrate pests and diseases constitute some of the important causes of seedling mortality. However, the quantification, impact and the effect of different plantation residue management practices on the incidence of these pests and diseases are unclear. Four trials were planted on previous pine sites, over four growing seasons. Four different plantation residue management regimes (windrow-burn-weed, complete-burn, fallow-weed, broadcast-chopper rolled) were tested. Seedlings were evaluated monthly after planting, for a period of one year. Stressed, damaged and dead seedlings were uprooted and inspected to determine the cause of death. The burning of pine plantation residue, irrespective of whether it was windrowed or broadcast and completely burnt, resulted in high outbreaks of the root rot pathogen, *Rhizina undulata*, in all species of *Pinus*. Mortality because of *R. undulata* infestation developed only after burning, and ranged from about 16% to 48%. Soil invertebrate pests, included whitegrubs, cutworms, *Hylastes angustatus*, grasshoppers and termites. They generally caused a low incidence of damage, which a range up to 9.51%, except when pines were grown in close proximity to wattle plantations, and where the incidence of whitegrub damage reached a maximum of 51.25%. The incidence of *H. angustatus* damage ranged from 0.25% to 5.83%. This strongly deviated from earlier perceptions of its importance because the causes of high mortality in *P. patula* seedlings were related to abiotic factors and site-species matching rather than *H. angustatus* damage. However, the inferred role of *H. angustatus* as a vector of fungal pathogens during the regeneration of pine seedlings, has elevated its pest status. Windrowing and burning of the plantation residue is standard management practice in some pine production areas, and this warrants a shift to the broadcasting of plantation residue. The current prophylactic application of an insecticide at planting was not cost effective but appeared necessary where

pines were grown in close proximity to wattle plantations and when regenerated late in the planting season. The routine use of insecticides is, however, restricted by Forest Stewardship Council guidelines.

Keywords: slash management, seedling mortality, soil invertebrate pests, root-rot pathogens, pines

INTRODUCTION

Commercial pine plantations have expanded at an annual rate of 1.2% during the past 20 years and currently occupy an area of 707 205 hectares of the total 1 330 943 hectares under forestry plantations in South Africa (Department of Water Affairs and Forestry 2001). These pine resources are used as sawn timber, veneer logs, pulpwood, paper, board and panel products, poles, firewood and charcoal. Burley *et al.* (1989) predicted that the demand for wood and wood products would increase by 3.1% per annum for the next 20 years, and proposed that this increased forest production was possible through the use of improved genetic material, cultural techniques and afforestation of low productivity sites. However, any attempt to improve the silvicultural gains of plantations is a meaningless exercise unless the health and survival of trees are ensured. Seedling survival contributes to the full stocking of compartments and eventually increased utilisable yield of the stand (Morris 1997).

The interactions of silvicultural practice and bark beetle pests on the survival of pine plantations have been extensively researched in southern Africa. Aspects of the ecology, phenology and control of the exotic bark beetles *Hylastes angustatus* Herbst, were investigated by Bevan & Jones (1971), Du Toit (1969, 1975) and Erasmus & Chown (1994), while Bevan (1984) reviewed *Orthotomicus erosus* Wollaston in Swaziland and parts of South Africa. Tribe (1990a, 1990b, 1991, 1992) studied the colonisation sites of three exotic bark beetle species on *Pinus radiata* D. Don logs and their phenology in the winter rainfall region of South Africa. However, most of these studies focused on the breeding sites of these beetles and not their impact on seedling mortality. Intensive investigations on the effects of planting date and site evaluation (Morris 1988a, 1990a), and harvesting plantation residue and climate (Morris 1990b) on the survival of *Pinus patula* Schlechtend seedlings were conducted in Swaziland. The phenology and impact of *H. angustatus* and other seedling mortality factors of *Pinus patula* seedlings were also studied in plantations in Swaziland (Simelane 1986, 1988, Morris 1988a, Morris 1990b). Morris (1991) consolidated previous interim reports into recommendations to improve the survival of pine seedlings in Swaziland. Atkinson & Govender (1997) investigated the phenology, effect of plantation residue management and chemical control of *H. angustatus* on *P. patula* seedlings in South Africa, where the total mortality was considered with no breakdown of the actual causes of mortality. The impact of soil invertebrate pests was inferred from responses to insecticides, which were often confounded by large, inexplicable mortality. Zhou *et al.* (2001) studied the ophiostomatoid fungi associated with pine infesting bark beetles in South Africa. Besides the study by Morris (1990b) in Swaziland, none of the studies in South Africa quantified the mortality caused by *H. angustatus*.

Many of the investigations into the re-establishment of burnt pine sites have focused on the mortality caused by the fungal root rot pathogen *Rhizina undulata* Fr. (Germishuizen 1984, Lundquist 1984, Morris 1988b) and its chemical control measures (Atkinson 1997). General silvicultural studies included the effect of water absorbent polymers and fertilisers in severely burnt sites (Allan & Carlson 1998), pit size treatments (Allan 1998), and site preparation (Boden 1984) on early growth and survival of pine seedlings. Although these practices improve tree growth they are not considered as requirements for ensuring the full stocking of a compartment (Morris 1997). It has been estimated that about 40% of *P. patula* plantings in Swaziland require replanting because of mortality by high post planting temperatures, the activity of *H. angustatus* and the quantity of harvesting plantation residue around the planting position (Morris 1991). Morris (1993, 1997) consequently evaluated the timing and impact of replanting operations.

During the move towards the intensive silviculture of plantations (Schönau 1990), the effects of plantation residue management regimes on the incidence of soil invertebrate pest and pathogen damage in the regeneration of pine plantations still remain unclear. The identity and status of indigenous soil invertebrate pests in pine regeneration in South Africa are clouded by the perception that *H. angustatus* is the most important pest. Our limited knowledge of the incidence of soil invertebrate pests is confounded by the different plantation residue management regimes. A prerequisite for the development of any plantation health management strategy is the identification of the insect pests and diseases that prevail over a range of plantation residue management regimes. The high establishment and management costs in commercial forestry would therefore raise the economic status of any destructive agents (Stone *et al.* 1997). This paper examines the suite of factors causing mortality in a range of regenerated pine species, to quantify the impact of pests and diseases so that a cost/benefit analysis of such control strategies can be obtained.

MATERIALS AND METHODS

Four trials were planted on previous pine sites over four growing seasons (1995/96 to 1999/00) to determine the mortality factors affecting the regeneration of pines. Sites were selected in different regions of the pine production area of South Africa, especially to cover the range of plantation residue management regimes practiced in those regions. In trial 1 (Bulwer: 29° 36′ S, 30° 08′ E) the plantation residue was completely burnt prior to planting in November. In trial 2 (Sabie: 25° 06′ S, 30° 46′ E) the plantation residue was broadcast but left fallow for about three years prior to planting in March. In trial 3 (Elandsdrift: 25° 12′ S, 30° 48′ E) the plantation residue was broadcast, chopper rolled and the planting pits mechanically prepared prior to planting in October. In trial 4 (Piet Retief: 26° 56′ S, 30° 33′ E) the plantation residue was windrowed and burnt prior to planting in April.

Seedlings were evaluated monthly for a period of one year after planting. Stressed, damaged and dead seedlings were dug together with approximately 0.012 m^3 of the surrounding soil to determine the cause of death. Mortality was determined according to the symptomatic damage caused by the various soil invertebrate pests and this was confirmed in many instances by the presence of the pest. Mortality was expressed as a percentage loss of establishment, where damage by soil invertebrate pests is equivalent to percentage infestation. Trials 1 and 2 were a randomised complete block design of five tree species (treatment plots) per replicate (total four) with 100 seedlings/plot. However, only two of the five tree species (wattle, *E. grandis*, *E. macarthurii*, or *Grandis* X *Urophylla* clone) were pines (*P. patula* and *P. elliottii*). Large trials with many trees per plot were planted because of the aggregate nature of soil invertebrate distributions (Allsopp & Bull 1989, Edwards 1991).

Besides soil invertebrate pest infestations, other mortality factors, especially pathogens were evaluated in trials 3 and 4 to determine the impact of pathogens in general. It was not possible to determine the incidence of pathogens with the symptomatic or pathogen isolation approach because most seedlings dried out during the monthly survey interval and the isolation for pathogens only showed saprophytes. Hence, an empirical methodology with an insecticide (chlordane 60% EC), fungicide (benomyl 50% WP) and a mixture of this insecticide and fungicide were used. Trials 3 and 4 involved a 5x5 latin square design with five tree species plots (treatments) and 120 seedlings/plot. Each plot was divided into five sub-plots of 24 seedlings. Each sub-plot was randomly treated with either an insecticide, or a fungicide, or mixtures of both and two sub-plots were untreated. The responses to these treatments compared to untreated plots were used to determine whether soil insect pests or pathogens were responsible for seedling mortality in instances where a diagnosis could not be made (seedling or pest absent, damage symptoms similar to other mortality factors or dry seedlings). The *Pinus* species and clonal cuttings that were tested were the plantation species considered most suitable for the particular trial site, and included *P. patula* and *P. elliottii* Engelm seedlings (both trials) and *P. gregii* Donahaue (trial 3), and a clonal hybrid GPVM (trial 4).

An analysis of variance (ANOVA) was carried out using Genstat for Windows^{TM} (Lane & Payne 1996) to test for statistically significant differences (Mead & Curnow 1983) within each of the trials. Additional ANOVA was undertaken for each of the mortality factors and surviving trees of each tree species in trials 3 and 4. Where statistically significant differences were detected, non-significant subsets were derived by Least Significant Differences (LSD's). These analyses allowed the testing of the validity of the symptomatic damage approach in order to adjust the recorded incidence of pests and diseases from other mortality factors when significant responses to pesticides were observed.

A pest database of extension visits and reported incidences of seedling damage (Pest & Diseases DataBase) was initiated at the start of these experiments. This was used to supplement the evaluation of the status of soil invertebrate pests and diseases and to justify the inclusion of a table on pests and diseases that were not observed in the trial series.

RESULTS AND DISCUSSION

Completely burnt site

The trial that was planted on this site experienced a 50.50% (*P. patula*) and 40.51% (*P. elliottii*) failure of seedlings to establish (Table 1). Of this, 95.05% (*P. patula*) and 86.00% (*P. elliottii*) of the total mortality was caused by the root rot pathogen *Rhizina undulata* (confirmed by the presence of fruiting bodies or sporophores). *Pinus patula* seedlings were significantly more susceptible to *R. undulata* than *P. elliottii* seedlings (ANOVA: $F_{4,57}$ = 48.71, $P < 0.01$), although the analysis of variance also included non-susceptible wattle and eucalypt seedlings. The higher susceptibility of *P. patula* is similar to Atkinson's (1997) observations. *Pinus patula* seedlings showed symptoms of *R. undulata* infestation soon after planting, whereas symptoms in *P. elliottii* seedlings were only observed after about two months. Site-species matching and other mortality factor effects were masked by the incidence of *R. undulata*. There was a negligible incidence (average of 0.5% for both pine species) of soil invertebrate pest (whitegrubs, cutworms, *Hylastes*) damage. Chafer beetles sporadically defoliate pines (Swain & Prinsloo 1986) and in the absence of *R. undulata*, one can expect an increased incidence of whitegrub damage. The removal of plantation residue and the scorching of stumps by fire also reduced the build up of *H. angustatus*, hence its low incidence. The *P. patula* and *P. elliottii* seedlings were older (with thicker stems) and therefore had a reduced incidence of cutworm damage. The planting of older nursery seedlings could be adopted as cultural control against cutworm attack if one can overcome the problems of disproportional root/shoot ratio and root bound seedlings. However, the topping of overgrown seedlings could also increase the incidence of nursery pathogens.

Fallow site

In the site where the plantation residue was broadcast after harvesting but left fallow for about three years before planting, there was a variable loss of establishment of seedlings between *P. patula* (27.01%) and *P. elliottii* (2.50%) (Table 1). There were sporadic and low incidences of damage by various soil invertebrate pests (cutworms, whitegrubs, termites, *Hylastes*, grasshoppers) in *P. patula* (4.13%) and *P. elliottii* (0.25%). The younger *P. patula* seedlings had a greater incidence of cutworm damage, which comprised 66.59% of the total mortality caused by soil invertebrate pests within this species. A dense grass cover and associated grasshopper population developed in the site during the fallow period, hence the low but regular incidence of grasshopper damage. Termites do not usually attack pine seedlings during their establishment (Swain & Prinsloo 1986), and a very low incidence of termite damage was observed. The dominant mortality factor causing loss of establishment in *P. patula* seedlings was assigned to the unknown category (22.63% out of a total 27.01%). This was most probably related to poor site-species matching of *P. patula* because the *P elliottii* seedlings showed superior survival and are regarded as a more suitable species choice for this site (Morris & Pallet 2000).

Table 1. Percentage loss of seedling establishment in different plantation residue management regimes during pine regeneration in South Africa. (values in bold have been adjusted following ANOVA).

MORTALITY FACTOR	CHOPPER ROLLED			WINDROWED, BURNT			COMPLETE BURN		FALLOW	
	P. patula	*P. elliottii*	*P. gregii*	*P. patula*	*P. elliottii*	GPVM	*P. patula*	*P. elliottii*	*P. patula*	*P. elliottii*
whitegrubs	0.83	1.25	1.04	42.57	51.25	**43.58**	0.00	0.50	0.25	0.00
cutworms	1.25	1.46	2.64	0.00	0.00	0.00	0.00	0.25	2.75	0.00
Hylastes	2.92	1.25	5.83	0.00	0.00	0.00	0.00	0.25	0.25	0.00
tipulids	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
millipedes	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
nematodes	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
wireworms	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
crickets	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
grasshoppers	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.63	0.25
ants	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
termites	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00
SOIL INVERT. PEST LOSS	*5.00*	*3.96*	*9.51*	*42.57*	*51.25*	*43.58*	*0.00*	*1.00*	*4.13*	*0.25*
browsing	2.08	0.63	0.21	0.00	2.92	0.83	0.25	1.63	0.00	0.25
pathogens	**2.18**	0.83	**1.62**	21.18	16.25	27.36	48.00	34.84	0.00	0.00
weed related	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.13	0.00	0.00
planting related	**0.11**	1.67	1.04	0.00	0.00	0.00	0.25	1.08	0.25	1.75
nursery related	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
abiotic	0.00	0.00	0.00	1.67	0.83	7.50	1.75	1.83	0.00	0.00
unknown	**35.21**	1.67	**58.03**	0.42	0.00	**0.31**	0.00	0.00	22.63	0.25
missing	0.00	0.42	0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL LOSS	*44.58*	*9.18*	*70.83*	*65.84*	*71.25*	*79.58*	*50.50*	*40.51*	*27.01*	*2.50*

Broadcast and chopper rolled site

In the site where the plantation residue was broadcast and chopper rolled prior to planting, there was much variation in the percentage of seedlings that failed to establish among the different *Pinus* species [*P. patula* (44.58%), *P. elliottii* (9.18%), *P. gregii* (70.83%)] (Table 1). There was also a variable incidence of soil invertebrate pest damage [*P. patula* (5.00%), *P. elliottii* (3.96%), *P. gregii* (9.51%)], which included whitegrubs, cutworms and *Hylastes*). Although the incidence of *Hylastes* damage in *P. patula* (2.92%) and *P. elliottii* (1.25%) seedlings was too low to detect any responses to the insecticide treatments, *P. gregii* seedlings showed highly significant responses to both the insecticide and fungicide treatments (ANOVA: $F_{4,80}$ = 1.58, P = 0.09). The response to a fungicide treatment is important in that it was long suspected that *H. angustatus* might be a possible vector or create wounds for the entry of fungal pathogens and this result demonstrates such an interaction. *Hylastes angustatus* was introduced into South Africa with a suite of fungi including various species that cause blue stain of sapwood (Zhou *et al.*, 2001). One of these fungi, *Leptographium serpens* (Goid.) M. J. Wingfield has also been linked to death of *P. radiata* D. Don. and *P. pinaster* Ait. in the Western Cape Province (Wingfield and Knox-Davies, 1980). Various species of *Fusarium* (fungal pathogen) have recently been isolated from pine seedlings in the nursery and in the field (Wingfield *et al.*, 1999). *Fusarium subglutinans* has both air and soil borne spores, which have been detected in the root collar region and roots of pine seedlings and was also isolated from *Hylastes* beetles (Pest & Diseases Database). *Hylastes angustatus* beetles ring girdle the root collar region of young seedlings (planted and naturally regenerated) during maturation feeding, where they require young green bark (obligatory feeding) for the proper maturation of their gonads (Bevan 1984). It is only in this phase that they are pests of pine re-establishment, and they are secondary pests during their breeding phase in stumps and roots. Their roles as vectors of fungal pathogens, however, would elevate their economic pest status, even if present in low numbers.

Pinus patula and *P. elliottii* seedlings were equally susceptible to *Hylastes* attack but *P. gregii* seedlings were significantly more susceptible than *P. patula* and highly significantly more susceptible than *P. elliottii* (ANOVA: $F_{4,12}$ = 6.34, P < 0.01). Morris (1991) reports that *P. patula* seedlings were more susceptible than either *P. elliottii* or *P. taeda* L. seedlings in Swaziland and recorded an average mortality of 12.5% by *Hylastes*, with a maximum of about 40%. Bevan & Jones (1971) observed that *Hylastes* did not immediately infest freshly harvested pine stumps as breeding sites and that there were different periods of post felling immunity and susceptibility for different pine species. These periods for *P. patula* (6-7 weeks, 2-8 months), *P. taeda* (2-5 months, 2-3 months up to 10), and *P. elliottii* (4-5 months, 4-5 months up to 12) were for post felling immunity and susceptibility respectively. Differences between the pine species were influenced by resin flow or content, where *P. elliottii* stumps sealed off quickly with resin (high content) and remained green for longer, while *P. patula* had less resin flow and the stumps dehydrated faster (Bevan & Jones 1971). Immunity of transplants is also related to bark thickness, which is attained after about two years (Morris 1991). Studies of the phenology of *Hylastes* on *P. radiata* in the winter rainfall region have shown the highest incidence of insects in September and October, where their activity peaks coincide with distinct climatic conditions, i.e. a mean temperature threshold of about 11.4°C occurring simultaneously with rainfall before flight activity (Tribe, 1990a). By contrast, in the summer rainfall region there are two to three overlapping generations per year, and maturation feeding occurs from October to April, where the seedlings require protection during this period (Atkinson & Govender, 1997, Morris 1990b, 1991). Hence the higher pest status of *H. angustatus* is in the summer rainfall areas. Susceptibility of seedlings to *Hylastes* attack can therefore be very variable and would be influenced by the previous plantation species, its harvesting date in relation to the time of planting, periods of peak maturation feeding, climatic conditions, and the effectiveness of site-species matching.

There was a low but regular incidence of cutworm damage and all pine species were equally susceptible despite the analysis of variance (ANOVA: $F_{4,12} = 6.81$, $P < 0.01$), which showed differences between the more susceptible eucalypt than pine seedlings. There was also a low but regular incidence of whitegrub damage in all pine species. Although the dominant soil invertebrate pest in most cases was *Hylastes*, the overall low incidences of soil invertebrate pests, demonstrates the need for an evaluation of the current general practice of preventatively applying insecticides at planting. This is feasible because there are differences in species susceptibility to *Hylastes* and cultural practices to avoid such an attack.

The largest portion of the loss of establishment of *P. patula* (35.21%) and *P. gregii* (58.03%) seedlings was attributed to the unknown category, which comprised 78.98% and 81.93% respectively of the total mortality of seedlings. There was no response to any of the pesticide treatments, which showed that neither soil invertebrate pests nor pathogens caused the mortality. This was most probably related to site-species matching because the *P. elliottii* seedlings, which are regarded as a more suitable species choice for this site (Morris & Pallet 2000), showed superior survival compared to *P. patula* and *P. gregii* seedlings. Significantly more *P. patula* seedlings survived than *P. gregii* but both these species experienced highly significantly more mortality than the *P. elliottii* seedlings (ANOVA: $F_{4,12}$ = 23.52, P < 0.001). There was also no response to the fungicide treatments in the suspected pathogen mortality category and these values were transferred to the unknown mortality category (ANOVA: $F_{4,80}$ = 1.02, P > 0.05). Once again there were significant species differences in the initial pathogen mortality category, where *P. patula* seedlings showed highly significantly less mortality than *P. gregii* but both of these species had highly significantly more mortality than *P. elliottii* (ANOVA: $F_{4,12}$ = 23.39, P < 0.001). This confirms that this is a site-species matching effect and that *P. elliottii* would be the preferred species choice for this site. Morris (1990b) reports that severe mortality in operational planting in Swaziland that was in the past blamed on the incidence of *Hylastes*, was probably related to climatic conditions at planting rather than *Hylastes*. Mortality attributed to the planting category in *P. patula* was transferred to the pathogen category because of a significant response to the fungicide treatment (based on LSD values despite no ANOVA support). Nursery pathogens often manifest in the field as a planting problem. It was observed that *P. patula* seedlings were significantly more susceptible to browsing damage than *P. gregii* seedlings (ANOVA: $F_{4,12}$ = 4.34, P < 0.05).

The low incidence of soil invertebrate pests and pathogens resulted in no responses to the pesticide treatments among surviving seedlings (Table 2) (ANOVA: $F_{4,80}$ = 1.01, P > 0.05), but definite differences in survival among the pine species. The survival of *P. elliottii* seedlings was highly significantly more superior than both *P. patula* and *P. gregii* seedlings, and highly significantly more *P. patula* seedlings survived than *P. gregii* seedlings (ANOVA: $F_{4,12}$ = 38.96, P < 0.001).

Table 2. Interaction of pesticide treatments in surviving pine seedlings in two widely practiced pine plantation residue management regimes in South Africa.

PESTICIDE TREATMENT versus CONTROL	Analysis of variance: difference of means					
	Broadcast, Chopper Rolled LSD: 5% (0.173), 1% (0.231)			Windrowed, Burnt LSD: 5% (0.172), 1% (0.229)		
	P. patula	*P. elliottii*	*P. gregii*	*P. patula*	*P. elliottii*	GPVM
Insecticide	0.056	0.060	0.015	0.243**	0.208*	0.234**
Fungicide	0.049	0.114	0.053	0.065	0.082	0.074
Mixture	0.122	0.098	0.085	0.504**	0.192*	0.238**

Windrowed and burnt site

In the trial where the plantation residue was windrowed and burnt prior to planting, there was a very large percentage of *Pinus* seedlings that failed to establish [*P. patula* (65.84%), *P. elliottii* (71.25%), GPVM (79.58%)] (Table 1). There was also a very high incidence of soil invertebrate pest damage [*P. patula* (42.57%), *P. elliottii* (51.25%), GPVM (43.58%)], which was dominated by whitegrubs. The polyphagous nature of whitegrub feeding was confirmed by the lack of differences in species susceptibility (ANOVA: $F_{4,12} = 0.71$, $P > 0.05$). There were, however, very highly significant responses to the insecticide treatments in all three pine species (ANOVA: $F_{4,80} = 33.57$, $P < 0.001$), confirming the symptomatic observation of whitegrub damage. The high incidence of whitegrub damage was related to the accumulative impact of root feeding by the late instar larvae of different whitegrub species (Govender, unpublished data), where there is an overlap of species that have a one or two year lifecycle (Sherry 1971). It also dispels the view that whitegrub larvae move deeper into the soil during autumn and winter (Fleming 1972) and are therefore outside the range of the root plugs of seedlings. There was a very low incidence of whitegrub damage in the other three pine trials that were planted in sites that were predominantly established to pine and eucalypts plantations. However, this trial was planted in southern Mpumalanga where large areas are also established to wattle plantations, which are often in close proximity to pine plantations. Chafer beetles (adult whitegrubs) sporadically cause extensive defoliation of both wattle and pine plantations in this area (Swain & Prinsloo 1986), and the larvae (whitegrubs) are the dominant soil invertebrate pests of wattle regeneration (Chapter 3). Hence the high incidence of whitegrub damage in pine regeneration in this region is not unexpected, although its impact was previously unknown.

Prior to planting, this trial site was aerially sprayed with a herbicide, to which a synthetic pyrethroid insecticide was added for cutworm control, hence the absence of cutworm damage. This is standard procedure in regions where the plantation residue is windrowed and burnt. Foresters often delay planting operations for several months after burning until the period of activity of the fungal pathogen *R. undulata* ceases (Germishuizen 1984, Lundquist 1984), so weeds usually colonise the site during the waiting period, which increases the possibility of cutworm attack (Chapter 4).

The second major mortality factor in all the pine species [*P. patula* (21.18%), *P. elliottii* (16.25%), GPVM (27.36%)] was caused by the fungal pathogen *Rhizina undulata* (fruiting bodies present during planting of the trial). There were very highly significant responses to the fungicide treatments in all three pine species, thereby confirming the presence of the pathogen (ANOVA: $F_{4,80} = 18.42$, $P < 0.001$). While *P. patula* seedlings were significantly more susceptible to *R. undulata* than *P. elliottii* seedlings in the trial where the plantation residue was completely burnt, in this windrowed and burnt trial, *P. patula* seedlings were equally susceptible to *R. undulata* as the *P. elliottii* and GPVM seedlings, but *P. elliottii* was significantly less susceptible than the GPVM seedlings (ANOVA: $F_{4,12} = 9.86$, $P < 0.001$). Overall though, there are no species of pine that have been identified as being resistant to *Rhizina* attack (Nichol 1992). The high incidence of *R. undulata* in this trial is a matter of concern especially since the windrowing and burning of pine plantation residue is a common site preparation practice in this region. Although growers claim that planting operations are delayed until *R. undulata* activity ceases, there is no consensus on the waiting period. This period has been recorded to vary from a few months (summer and autumn in South Africa) to six years after the fire (in the Northern Hemisphere) (Atkinson 1997). The current recommendation for the regeneration of burnt sites in South Africa, besides the use of fungicides at planting (Atkinson 1997), is to plant successive test plots to determine *R. undulata* activity prior to planting (Wingfield & Swart 1994).

In the unknown mortality category of the GPVM seedlings, there were significant responses to the insecticide treatments, so this was moved to the whitegrub mortality category (ANOVA: $F_{16,80} = 2.96$, $P < 0.001$). The abiotic mortality category refers to suspected frost damage where symptomatic assessments were unreliable and the treatment effects were confounded. There were species differences in browsing susceptibility (ANOVA: $F_{4,12} = 5.82$, $P < 0.01$), with the GPVM and *P. patula* seedlings being equally susceptible but less so than the *P. elliottii* seedlings. This result conflicts with the observations on browsing susceptibility in the chopper rolled trial and suggests that browsing is probably related to surviving trees being more healthy and available for browsing, rather than a pine tree species effect. However, all pesticide treated *P. elliottii* and GPVM seedlings were significantly less browsed than untreated seedlings suggesting that the smell of the pesticide acted as a deterrent to browsing.

A comparison of the surviving trees of all pine species showed that there were significant responses to the insecticide and insecticide/fungicide mixture treatments but not the fungicide treatments (ANOVA: $F_{4,80} = 15.42$, $P < 0.001$) (Table 2). Responses to the insecticide treatments were expected because of the high incidence of whitegrub damage but the same reasoning did not hold true for the high incidence of *R. undulata* infestations. It is postulated that although seedlings were protected from *R. undulata* infestation because of the fungicide treatment, they subsequently became susceptible to whitegrub attack, hence the lack of a response to the fungicide treatment in seedlings that survived. There were differences in survival among the pine species, where *P. elliottii* was equivalent to GPVM and *P. patula* seedlings but significantly more *P. patula* than GPVM seedlings survived (ANOVA: $F_{4,12} = 12.50$, $P < 0.001$). These differences were, however, inconsequential in relation to the incidence of pests and diseases. Factors that impede rapid growth such as poor site quality, drought, frost and weed competition also tend to increase exposure to, and delay the recovery, from insect pests and diseases (Stone *et al.* 1997).

Other pine establishment pests

Several other pests that were recorded over a fourteen-year period from extension visits and samples submitted for diagnosis or identification (Pest & Diseases Database), affect the establishment of pine seedlings, but were not encountered in this study. A list of those pests affecting pine seedlings and saplings, the most commonly recorded hosts, and a brief commentary of occurrence and damage are presented in Table 3.

Table 3. List of damaging invertebrate, animal agents and pathogens and their main hosts during pine establishment in southern Africa. Extracted from Pest & Diseases Database of extension reports.

Scientific name	Common name	Most commonly recorded hosts	Comments
ORTHOPTERA			
Mecostibus pinivorus [Lentuilidae]	grasshoppers	*P. patula*	occasional damage to very young trees in Zimbabwe
Zonoceres elegans (Thunberg) [Pyrgomorphidae]	elegant grasshopper	*P. patula, P. elliottii*	occasional defoliation of seedlings on burnt sites
COLEOPTERA			
Colasposoma fulgidum Lefevre [Chrysomelidae]	green & bronze	*P. patula*	sporadic but severe defoliation of seedlings, larvae feed on roots, seedling deaths sometimes reported
Colasposoma pusillum Jacoby [Chrysomelidae]	green & bronze	*P. radiata*	defoliation of seedlings
Colasposoma semihirsutum Jacoby [Chrysomelidae]	green & bronze	*P. radiata*	defoliation of seedlings
Hypopholis sommeri Burmeister [Scarabaeidae]	chafers	*P. patula*	sporadic defoliation by adults
numerous undescribed species [Scarabaeidae]	whitegrub larvae	*P. patula, P. elliottii, P. taeda, P. gregii,* GPVM hybrid	severe damage as root feeders
Heteronychus arator Fabricius [Scarabaeidae]	black maize beetle	*P. patula*	adults strip bark off seedlings, ex-maize lands
Protostrophus sulcatifrons (Marshall) [Curculionidae]	ground weevil	*P. patula, P. radiata*	occasional defoliation
Hylastes angustatus (Herbst) [Scolytidae]	bark beetle	*P. patula*	underbark girdling of root collar of seedlings, larvae & adults
Pissodes nemorensis Germar [Curculionidae]	pine snout beetle		larvae girdle root collar of seedlings in coastal areas
LEPIDOPTERA			
Agrotis spp. [Noctuidae]	cutworms	*P. patula, P. elliottii, P. gregii,*	sporadic damage to young seedlings severs stem at ground level
HEMIPTERA			
Cinara cronartii Tissot & Pepper [Aphididae]	black pine aphid	*P. patula*	occasional sap sucker
Pineus pini (Linnaeus) [Aphididae]	pine woolly aphid	*P. radiata*	occasional sap sucker
THYSANOPTERA			
Heliothrips haemorrhoidalis (Bouche) [Thripidae]	thrips	*P. patula*	occasional damage to pine needles
ISOPTERA			
Hodotermes mossambicus (Hagen) [Hodotermitidae]	termites	*P. patula*	occasional root and bark feeder
RODENTIA			
Otomys irroratus Brants	vlei rat	*P. patula*	during afforestation of grassland areas
Rhabdomys pumilio Sparrman	striped mouse	*P. elliottii*	during afforestation of grassland areas
PATHOGENS			
Fusarium oxysporum		*P. patula, P. elliottii*	nursery seedlings and infield mortality
Fusarium subglutinans		*P. patula, P. gregii*	nursery seedlings and infield mortality
Rhizina undulata	pine root rot	*P. patula, P. elliottii P. radiata, P. gregii* GPVM hybrid	regenerated pine seedlings after fire
Verticillium sp.		*P. elliottii*	nursery seedlings and infield mortality
Cylindrocarpon sp.		*P. elliottii*	nursery seedlings and infield mortality
Cylindrocladium sp.		*P. elliottii*	nursery seedlings and infield mortality
Sphaeropsis sapinea		*P. elliottii X carribea*	endophyte, stress related

Plantation residue management considerations

Burning of pine plantation residue, including windrowing and burning, is associated with high outbreaks of the root pathogen *R. undulata*. The success with delaying the planting of such sites until the activity of *R. undulata* ceases is variable and uncertain. These delays could postpone planting to the next growing season, which would result in a loss of productivity. The alternative practice of preventatively treating with broad-spectrum fungicides at planting is environmentally undesirable and carries the risk of pathogens developing resistance to frequently used fungicides. In some areas there is the additional risk of damage by soil invertebrate pests, especially whitegrubs, which require the application of an insecticide treatment. The use of pesticides to protect pine seedlings form pest and disease attack conflicts with the certification principles and criteria of the Forestry Stewardship Council (FSC), where certified plantations are expected to show a phased reduction of pesticide use until alternative control measures can be developed (Govender 2002).

Principles and criteria of the FSC also require that forestry operations are designed to avoid or mitigate adverse environmental impacts, and that forest damage be minimised. Plantation residue should be broadcast or stacked in rows (windrowed) along the contour; and burning is acceptable only under cool burn conditions (Qualifor 2002). Although the burning of pine plantation residue falls into a grey area, the development of *R. undulata* infestation as a result of burning operations consequently disqualifies this practice.

Broadcasting the plantation residue rather than burning has apparently increased damage by *H. angustatus* bark beetles. This ill-founded perception was often based on the observations of total mortality of seedlings and not the causes. For example, the regeneration of *P. patula* seedlings in Swaziland were associated with severe mortality (about 50%), particularly when planted into broadcast plantation residue, but the mortality associated with *H. angustatus* attack only averaged 12.5% (Morris 1990b). There were very few cases of *H. angustatus* feeding on pruned or plantation harvest residue because of their rapid desiccation under southern African conditions. Instead there was lower breeding activity in cut stumps in broadcast plots because insulation of the soil reduced the soil temperature required for breeding, compared to slash cleared plots. Overall though, total mortality of *P. patula* seedlings was more severe where the residue was broadcast because of the high planting position temperature within those sites (Morris 1990b). Similarly in this study there was a low incidence of *H. angustatus* damage in the trial where the residue was broadcast, and the low mortality of *P. elliottii* seedlings showed that they were less affected by site quality or temperature regime compared to *P. patula* and *P. gregii* seedlings. This demonstrates the importance of site-species matching.

Broadcasting of plantation residue, without the use of preventative insecticides at planting, would incur some mortality by soil invertebrate pests and necessitate the replanting of these seedlings. As short a time interval as possible between first planting and replanting is preferred with both occurring in the same planting season. Delayed replanting operations result in variable tree size, where these small subdominant trees contribute little to final yield or die before rotation age is reached (Morris 1997). It is also important to ensure that nursery seedlings are healthy and disease free.

ACKNOWLEDGEMENTS

I thank the Institute for Commercial Forestry Research and the Forestry & Agricultural Biotechnology Institute, South Africa, and its patron forestry companies for funding and supporting this research. I am particularly grateful to the many forestry personnel of SAPPI and MONDI, who assisted with the planting and maintenance of the various trials. I also thank Prof. Clarke Scholtz for reviewing the manuscript and Prof. G. P. Y. Clarke (University of Natal) for statistical assistance.

REFERENCES

Allan, R. 1998. A report on pit size treatments and how these impact on tree growth and survival. *ICFR Bulletin Series 11/97*. Institute for Commercial Forestry Research, University of Natal, Pietermaritzburg.

Allan, R. & Carlson, C. 1998. Report on trial SP96/03: an investigation into the re-establishment of severely burnt sites. *ICFR Bulletin Series 11/97*. Institute for Commercial Forestry Research, University of Natal, Pietermaritzburg.

Allsopp, P. G. & Bull, R. M. 1989. Spatial patterns and sequential sampling plans for melolonthine larvae (Coleoptera: Scarabaeidae) in southern Queensland sugarcane. *Bulletin of Entomological Research* **79:** 251-258.

Atkinson, P. R. 1997. Diseases of pine at establishment, primarily *Rhizina undulata* Fr.: results of field experiments. *ICFR Bulletin Series 11/97*. Institute for Commercial Forestry Research, University of Natal, Pietermaritzburg.

Atkinson, P. R. & Govender, P. 1997. Mortality of *Pinus patula* seedlings due to *Hylastes angustatus* (Herbst) (Coleoptera: Scolytidae). *ICFR Bulletin Series 8/97*. Institute for Commercial Forestry Research, University of Natal, Pietermaritzburg.

Bevan, D. 1984. *Orthotomicus erosus* (Wollaston) in Usutu pine plantations, Swaziland. *Forest Research Report No. 64*. Usutu Pulp Company. Mbabane, Swaziland.

Bevan, D. & Jones, T. 1971. Report on the beetle *Hylastes angustatus* in pine plantations of Swaziland and adjacent areas of the Republic of South Africa. Forestry Commission Research and Development Paper No. 84, Forestry Commission, London.

Boden, D. I. 1984. Early responses to different methods of site preparation for three commercial tree species. Proceedings of IUFRO Symposium, Pretoria and Pietermaritzburg, South Africa, 30 April-11 May 1984. In: D. C. Grey, A. P. G. Schönau, C. J. Schutz and A. van Laar (Eds.): *Site and productivity of fast growing plantations* Volume **2:** 565-578.

Burley, J., Armitage, F. B., Barnes, R. D., Gibson, G. L., Hardcastle, P. D., Huguet, L., Plumptre, R. A. & Wood, P. J. 1989. Forestry research in eastern and southern Africa. *Tropical Forestry Papers No. 19*. Oxford Forestry Institute, London.

Department of Water Affairs and Forestry. 1980 - 2001. Report on commercial timber resources and roundwood processing in South Africa. 1980-2001. Pretoria.

Du Toit, P. F. 1969. Die bio-ekologie en bestryding van die baskewer, *Hylastes angustatus* Herbst (Coleoptera, Scolytidae). *MSc thesis*. University of Pretoria, Pretoria.

Du Toit, P. F. 1975. Aspekte van die bio-ekologie en bestryding van die baskewer, *Hylastes angustatus* Herbst (Coleoptera, Scolytidae). *Bosbou in Suid-Afrika* **16:** 37-43.

Edwards, C. A. 1991. The assessment of populations of soil-inhabiting invertebrates. *Agriculture, Ecosystems and Environment* **34:** 145-176.

Erasmus, M. J. & Chown, S. L. 1994. Host location and aggregation behaviour in *Hylastes angustatus* (Herbst) (Coleoptera: Scolytidae). *African Entomology* **2:** 7-11.

Fleming, W. E. 1972. Biology of the Japanese beetle. *Agricultural Research Service Technical Bulletin No. 1449.* United States Department of Agriculture, Washington.

Germishuizen, P. J. 1984. *Rhizina undulata* - a pine seedling pathogen in South Africa. Proceedings of IUFRO Symposium, Pretoria and Pietermaritzburg, South Africa, 30 April-11 May 1984. *In:* D. C. Grey, A. P. G. Schönau, C. J. Schutz and A. van Laar (Eds.): *Site and productivity of fast growing plantations* Volume **2:** 753-765.

Govender, P. 2002. Management of insect pests: Have the goalposts changed with certification? *Southern African Forestry Journal* **195:** 39-45.

Lane, P. W. & Payne, R. W. 1996. *Genstat, for Windows^{TM} an introductory course*. The Numerical Algorithms Group Limited, United Kingdom.

Lundquist, J. E. 1984. The occurrence and distribution of *Rhizina* root rot in South Africa. *South African Forestry Journal* **131:** 22-24.

Mead, R. & Curnow, R. N. 1983. *Statistical methods in agriculture and experimental biology.* Chapman and Hall, London.

Morris, A. R. 1988a. Report on trial series R115: Influence of felling and planting date on mortality of *Pinus patula* transplants caused by *Hylastes angustatus*. *Forest Research Document 11/88*. Usutu Pulp Company. Mbabane, Swaziland.

Morris, A. R. 1988b. *Rhizina undulata* activity following wild fire in the Usutu forest. *Forest Research Document 13/88.* Usutu Pulp Company. Mbabane, Swaziland.

Morris, A. R. 1990a. Report on trial series R125: Mortality of *Pinus patula* transplants due to *Hylastes angustatus* attack in relation to planting date and site evaluation. *Forest Research Document 8/90*. Usutu Pulp Company. Mbabane, Swaziland.

Morris, A. R. 1990b. Report on trial series R133: Harvesting slash, *Hylastes angustatus* and climate as factors influencing *Pinus patula* transplant survival. *Forest Research Document 9/90*. Usutu Pulp Company. Mbabane, Swaziland.

Morris, A. R. 1991. Recommendations to improve transplant survival for re-establishment in the Usutu forest. *Forest Research Document 3/91*. Usutu Pulp Company. Mbabane, Swaziland.

Morris, A. R. 1993. Interim report trial R135: Height growth at 21 months in a time of blanking trial. *Forest Research Document 2/93*. Usutu Pulp Company. Mbabane, Swaziland.

Morris, A. R. 1997. Five-year results from a blanking trial with *Pinus patula*. *Southern African Forestry Journal* **178:** 1-7.

Morris, A. & Pallett, R. 2000. Site requirements and species matching: Pines. In: Owen, D. L. ed. *South African Forestry Handbook.* pp. 80-84. South African Institute of Forestry, Pretoria.

Nichol, N. S. 1992. *Rhizina undulata* in South Africa. *ICFR Bulletin Series 21/92*. Institute for Commercial Forestry Research, University of Natal, Pietermaritzburg.

Pest & Diseases Database. 2002. Forestry and Agricultural Biotechnology Institute, University of Pretoria, Pretoria, South Africa.

Qualifor, 2002. Forest management certification: main assessment checklist (South Africa). Quality Forest Management - SGS Forestry. Oxford, United Kingdom. *Unpublished Draft*. (http://www.qualifor.com).

Schönau, A. P. G. 1990. Role of eucalypt plantations in timber supply and forest conservation in sub-saharan Africa. Proceedings of 19th IUFRO World Congress, Montreal, Canada, Division **2:** 311-319.

Sherry, S. P. 1971. *The Black Wattle* (Acacia mearnsii *De Wild*). University of Natal Press, Pietermaritzburg.

Simelane, T. L. 1986. A review of the pine bark beetle *Hylastes angustatus* Herbst. *Forest Research Document 1/86*. Usutu Pulp Company. Mbabane, Swaziland.

Simelane, T. L. 1988. Observations on the breeding cycle of *Hylastes angustatus* on clearfelled sites in the Usutu Forest, Swaziland. *Forest Research Document 12/88*. Usutu Pulp Company. Mbabane, Swaziland.

Stone, C., Simpson, J. A. & Eldridge, R. H. 1997. Insect and fungal damage to young eucalypt trial plantings in northern New South Wales. *Australian Forestry* **61:** 7-20.

Swain, V. M. & Prinsloo, G. L. 1986. A list of the phytophagous insects and mites on forest trees and shrubs in South Africa. *Entomology Memoir* **66:** 1-91.

Tribe, G. D. 1990a. Phenology of *Pinus radiata* log colonisation by the pine bark beetle *Hylastes angustatus* (Herbst) (Coleoptera: Scolytidae) in the South-Western Cape Province. *Journal of the Entomological Society of Southern Africa*, 53, 93-100.

Tribe, G. D. 1990b. Phenology of *Pinus radiata* log colonisation and reproduction by the European bark beetle *Orthotomicus erosus* (Wollaston) (Coleoptera: Scolytidae) in the South-Western Cape Province. *Journal of the Entomological Society of Southern Africa*, 53, 117-126.

Tribe, G. D. 1991. Phenology of *Pinus radiata* log colonisation by the red-haired pine bark beetle *Hylurgus ligniperda* (Fabricius) (Coleoptera: Scolytidae) in the South-Western Cape Province. *Journal of the Entomological Society of Southern Africa*, 54, 1-7.

Tribe, G. D. 1992. Colonisation sites on *Pinus radiata* logs of the bark beetles, *Orthotomicus erosus, Hylastes angustatus* and *Hylurgus ligniperda* (Coleoptera: Scolytidae). *Journal of the Entomological Society of Southern Africa*, 55, 77-84.

Wingfield, M. J. & Knox-Davies, P. S. 1980. Root disease, associated with *Verticicladiella alacris*, of pines in South Africa. *Plant Disease* **64:** 569-571.

Wingfield, M. J. & Swart, W. J. 1994. Integrated management of forest tree diseases in South Africa. *Forest Ecology and Management* **65:** 11-16.

Wingfield, M. J., Wingfield, B. D., Coutinho, T. A., Viljoen, A., Britz, H. & Steenkamp, E. T. 1999. Pitch canker: A South African perspective. Proceedings of the IMPACT Monterey Workshop. Monterey, California. *In*: Devey M., Matheson C., Gordon T. (Eds.) : *CSIRO Forestry and Forest Products Technical Report* **112:** 62- 69.

Zhou, X., De Beer, Z. W., Wingfield, B. D. & Wingfield, M. J. 2001. Ophiostomatoid fungi associated with three pine-infesting bark beetles in South Africa. *Sydowia* **53:** 290-300.

CHAPTER 7

Management of insect pests - have the goalposts changed with certification?

Govender, P. 2002. Management of insect pests: Have the goalposts changed with certification? *South African Forestry Journal* **195:** 39-45. (dedicated journal edition and invited oral presentation at Woodfor Africa 2002, Pietermaritzburg, South Africa)

ABSTRACT

The certification of commercial forestry according to the Forest Stewardship Council (FSC) specifications has successfully occurred in many South African plantations and this trend is set to increase in the future. Various principles and criteria govern the management of insect pests in certified forests, which differ from traditional control measures. Regulations on the use of insecticides, biocontrol agents, monitoring, assessment and management of insect pests have become more specific. World Health Organisation type 1a and 1b, chlorinated hydrocarbons and persistent, toxic and bioaccumulative insecticides are prohibited. Only *Bacillus thuringiensis* is acceptable from the about twelve insecticides currently used in forestry. The use of biological control agents needs to be monitored and documented, but their future uses, as a control measure needs to be minimised. The general flora and fauna, and especially insect pest species must be regularly monitored and the results incorporated into an ongoing management plan. A summary of monitoring indicators should be made available to the public. An integrated pest management approach for the control of insect pests is advocated but with restrictions on the use of insecticides and biological control. Although the FSC management plan for the control of insect pests would certainly contribute to the sustainability of commercial plantations in the future, it poses many challenges in the short term.

Keywords: forest insect pests, management, FSC certification, principles and criteria

INTRODUCTION

The South African forestry industry consists of a total of about 1,4 million hectares of intensively managed commercial plantations (Department of Water Affairs and Forestry, 2000). These are composed of exotic tree species, including those of *Pinus*, *Eucalyptus*, and *Acacia mearnsii*. Sawlogs, veneer logs, pulpwood, mining timber, poles, matchwood, charcoal and firewood are examples of products from these commercial forestry operations. Several international consumers of especially sawlogs, veneer logs and pulpwood are, however, selecting, and creating demand for, products that can be traced back to a sustainable and environmentally friendly forestry operation. Certified forestry products that can be traced from their origin, a process known as the "chain of custody", are therefore preferred. About 75% of the forestry enterprises in South Africa have opted to structure and manage their plantations according to the Forest Stewardship Council (FSC) specifications so that they may further enhance their competitiveness in the export market (Kevin Cazalet, personal communication).

The FSC has revised several draft discussion papers, which stipulate the Principles and Criteria of Forest Stewardship (Qualifor, 2002). Compliance with these laws and FSC principles determine whether a plantation will be FSC certified or not. This paper seeks to interpret those Principles and Criteria that relate to the management of insect pests, and evaluates the control strategies and implications of such measures from a South African forestry perspective.

SUMMARY OF THE INCIDENCE AND MANAGEMENT OF IMPORTANT FORESTRY PESTS

Besides pathogens, numerous indigenous and exotic insect pests attack plantation tree species, both during establishment and their post-establishment growth phases. South Africa has a concomitant history of entomological research of management strategies against these pests.

A complex of indigenous soil invertebrate pests contributes to about a 23% failure of all species of seedlings from establishment (Govender, 1995). This failure to achieve full stocking of compartments affects the yield of plantation forestry and also increases the cost of silvicultural operations, for example, additional blanking, weeding and pest control operations. Millipedes (Diplopoda: Juliformia: *Orthoporoides* spp.), cutworms (Lepidoptera: Noctuidae: *Agrotis segetum*), whitegrubs (Coleoptera: Scarabaeidae: *Hypopholis sommeri*), wireworms (Coleoptera: Tenebrionidae: *Somaticus* spp.), grasshoppers (Orthoptera: Pyrgomorphidae: *Zonocerus elegans*) and crickets (Orthoptera: Gryllidae: *Gryllus bimaculatus*) are examples of some of the indigenous insects that attack wattle, pine and eucalypt seedlings (Govender 1995). Wattle and eucalypt seedlings are also susceptible to attack by termites (Isoptera: Termitidae: *Macrotermes natalensis*), tipulid larvae (Diptera: Tipulidae: *Nephrotoma* spp.) and various snout beetles (Coleoptera: Curculionidae: *Ellimenistes laesicollis, Protostrophus* spp.). Pine seedlings are also susceptible to attack by bark beetles (Coleoptera: Scolytidae: *Hylastes angustatus*), nematodes (Nematoda: *Meloidogyne* spp.) and leaf beetles (Coleoptera: Chrysomelidae: *Colasposoma spp.*).

Four exotic pests affect established *Eucalyptus* in South Africa. The eucalypt snout beetle, *Gonipterus scutellatus* (Coleoptera: Curculionidae), a defoliator, is under effective biological control by the egg parasitoid *Anaphes nitens*, but often fails in high altitude areas (Tooke 1955). The eucalypt tortoise beetle, *Trachymela tincticollis* (Coleoptera: Chrysomelidae), another defoliator, is also under effective biological control by an egg parasite (*Enoggera reticulata*) (Tribe & Cillie 1997). Two longhorn beetles, *Phoracantha semipunctata* and *P. recurva* (Coleoptera: Cerambycidae) damage the wood of drought stressed and recently felled trees (Tooke 1928). The egg parasitoid, *Avetianella longoi* is now established and several larval parasitoids (*Syngaster lepidus, Jarra maculipennis, Jarra phoracanthae*) are being evaluated as biocontrol agents for the longhorns (Kirsten *et al.* 2000).

All the wattle pests are endemic to South Africa. *Chaliopsis junodi* (wattle bagworm) (Lepidoptera: Psychidae) is the most serious wattle pest, and economically, the most important of the lepidopteran defoliators, while *Achaea lienardi* (wattle semi-looper) (Lepidoptera: Noctuidae) and *Gynanisa maia* (emperor) (Lepidoptera: Saturniidae) are sporadic pests (Sherry 1971). Adult *Hypopholis sommeri* (wattle chafer) (Coleoptera: Scarabaeidae) occasionally defoliate established wattle and pine plantations. The wattle mirid, *Lygidolon laevigatum* (Hemiptera: Miridae), is the second most serious pest that causes multiple branching and defoliation of young trees (Sherry 1971).

Three indigenous lepidopteran pests, [*Imbrasia cytherea* (Saturniidae), *Pachypasa capensis* (Lasiocampidae) and *Euproctis terminalis* (Lymantriidae)] regularly defoliate species of pines (Kirsten *et al.* 2000). All other pine pests are exotic. The pine weevil, *Pissodes nemorensis* (Coleoptera: Curculionidae) damages the root collar region of saplings and causes dieback of the terminal shoots of established trees (Van V. Webb 1974). The pine woolly aphid, *Pineus boerneri* (Hemiptera: Adelgidae), causes economic damage, especially in the winter rainfall region (Barnes *et al.* 1976, Bruzas 1983). The black pine aphid, *Cinara cronartii* (Hemiptera: Aphididae), is under effective biological control by a parasitic wasp (*Pauesia cinaravora*) (Van Rensburg 1981), while the pine needle aphid, *Eulachnus rileyi* (Hemiptera: Aphididae), does not appear to cause economic damage (Marchant 1989). The bark beetle *Hylastes angustatus* occasionally causes sporadic damage (Tribe 1990a), while *Orthotomicus erosus* (Coleoptera: Scolytidae) is responsible for vectoring the blue stain fungus (Tribe 1990b). The pine wood wasp, *Sirex noctilio* (Hymenoptera: Siricidae), has entered the country and has rapidly spread within the Southern and Western Cape during the last seven years (Tribe 1995). Biocontrol using the parasitic nematode (*Deladenus siricidicola*) has shown limited efficacy and the introduction of additional hymenopteran parasitoids (*Ibalia leucospoides, Megarhyssa nortoni, Rhyssa persuasoria*) on the different life stages of *S. noctilio* is at a preliminary level.

FSC PRINCIPLES AND CRITERIA IN CERTIFIED FORESTS

Several FSC Principles and Criteria were drafted for the management of insect pests (Qualifor, 2002). Each of these, and their implications are evaluated against current pest control measures. In some instances, I believe that representation by the South African Forest Industry to amend and address anomalies in the draft FSC Principles and Criteria are warranted.

Use of insecticides

Criterion 6.6. "Management systems shall promote the development and adoption of environmentally-friendly non-chemical methods of pest management and strive to avoid the use of chemical pesticides. World Health Organisation (WHO) Type 1a and 1b and chlorinated hydrocarbon pesticides, pesticides that are persistent, toxic or whose derivatives remain biologically active and accumulate in the food chain beyond their intended use, as well as any pesticides banned by international agreement, shall be prohibited. If chemicals are used, proper equipment and training shall be provided to minimise health and environmental risks" (Qualifor, 2002).

WHO type 1A and 1B and chlorinated hydrocarbons

This criterion has received the most attention by researchers associated with forestry (McNamara, 2002; Radosevich *et al.*, 2000; Synnott, 2000; Weir, 2001). FSC requires that there is a list of all chemicals used by an organisation and that prohibited chemicals are not used. Although numerous lists exist in the different forestry organisations, the list that appears in the South African Forestry Handbook (2000) is used as a point of reference in this paper (Kirsten *et al.*, 2000). Insecticidal treatments are presented for six of the about 13 important soil pests that affect the establishment of seedlings and three of the about 19 important insect pests that damage established trees (**Table 1**). The following insecticide treatments which appear on the list, are not registered for use in forestry in South Africa and therefore cannot and should not be recommended: carbaryl 85% WP (grasshoppers), methiocarb 80% WP (millipedes), cypermethrin 20% EC (wattle mirid) and diflubenzuron 25% WP (wattle bagworm) (Nel *et al.*, 1999). Furthermore, pesticides that are categorised as WHO classes 1a and 1b and chlorinated hydrocarbons are prohibited from use in certified forests. These pesticides are generally environmentally persistent, bioaccumulative, feto-toxic, have central nervous system activity and endocrine disrupting properties (Radosevich *et al.*, 2000). Gamma BHC 0.6% D (*Hylastes*, whitegrubs), chlordane 60% EC (termites), alphacypermethrin 10% EC (emperor moth larvae, wattle bagworm), endosulfan 47.5% SC and 35% EC (emperor moth larvae) therefore also need to be excluded from the list (**Table 1**).

Table 1. List of insecticide treatments for use against pests attacking plantation trees in South Africa

Pest	Tree species	Active ingredient formulation	Class, Hazard group
		ESTABLISHMENT	
Elegant grasshopper	Many crops	*Carbaryl 85% WP*	Carbamate, II
Hylastes	Pines	**Gamma BHC 0,6% D** Deltamethrin 5% SC	**Organochlorine**, IV Pyrethroid, IV
Millipedes	Many crops	*Methiocarb 80% WP*	Carbamate, II
Termites	Eucalypts and wattle	***Chlordane 60% EC*** Carbosulfan 10% CG	**Organochlorine**, II Carbamate, IV
Whitegrubs	Pines, wattle and eucalypts	**Gamma BHC 0,6% D** Deltamethrin 5% SC Carbosulfan 10% CG	**Organochlorine**, IV Pyrethroid, IV Carbamate, IV
Cutworms	Pines, wattle and eucalypts	Deltamethrin 5% SC	Pyrethroid, IV
		POST ESTABLISHMENT	
Emperor moth larvae	Pines	**Alphacypermethrin 10% EC** Alphacypermethrin 10% SC Cypermethrin 20% EC Cypermethrin high cis 20% EC **Endosulfan 47,5% SC** **Endosulfan 35% EC** *Bacillus thuringiensis* var. *kurstaki* SC, WP	Pyrethroid, **Ib** Pyrethroid, IV Pyrethroid, II Pyrethroid, II Organochlorine, **Ib** Organochlorine, **Ib** Microbial, III
Wattle mirid	Wattle	Deltamethrin 2,5% EC Acephate 75% SP *Cypermethrin 20% EC*	Pyrethroid, II Organophosphate, III Pyrethroid, II
Wattle bagworm	Wattle	**Alphacypermethrin 10% EC** Alphacypermethrin 10% SC Betacyfluthrin 5% EC Cyfluthrin 5% EC Cypermethrin 20% EC Cypermethrin high cis 20% EC *Diflubenzuron 25% WP*	Pyrethroid, **Ib** Pyrethroid, IV Pyrethroid, II Pyrethroid, II Pyrethroid, II Pyrethroid, II Benzoylurea, IV

* List of insecticidal treatments extracted from Kirsten *et al.* (2000). Source for hazard groups: M. Krause (National Department of Agriculture). Treatments in bold are FSC prohibited; in italics are not registered for use in forestry.

Persistent, toxic or bio-magnifying insecticides

The principles of the FSC further restrict the types of insecticides that can be used against forestry pests to those that are neither toxic nor persistent and that do not bioaccumulate up the food chain. According to the proposed criteria, a qualifying insecticide is one that passes all the relevant criteria described in Radosevich *et al.* (2000). An insecticide, which under the conditions of use, persists or can reasonably be expected to persist in its originally used formulation or a toxicologically comparable active form for 100 days or more shall be considered persistent, and prohibited. Pesticides with a standard Reference Dose (RfD) of less than 0.01 mg/kg/day are prohibited (acceptable daily intake (ADI) values were used for lack of RfD values in this evaluation). Pesticides with an overall 50% Lethal Dose (LD_{50}) level of less than 200 mg/kg, taking account of all active ingredients in the formulation, including wetting agents, surfactants and solvents, are prohibited (the rat was used as a standard example). Pesticides with an aquatic toxicity of LC_{50} of less than 0.05mg/L in aquatic environments are prohibited (the rainbow trout was used as a standard example). The bioaccumulation of pesticides or their biologically active derivatives in the fat or lipid of individual organisms, and their bioconcentration to higher trophic levels, is measured by the octanol-water partition coefficient. A pesticide is prohibited if the octanol-water differential gradient (Kow) is over 1000 (or logKow greater than 3). Pesticides containing lead (Pb), cadmium (Cd), arsenic (As), or mercury (Hg) are prohibited. Any pesticide contaminated with dioxins with a TCDD equivalence of 10 ppt or greater, or which produces such dioxin when burned, is permanently prohibited. Chemicals are also prohibited if they are categorised by various Environmental Protection Agencies as carcinogenic, mutagenic or endocrine disruptors (Radosevich *et al.*, 2000; Synnott, 2000).

Using some of the above criteria, where information was available, examples of insecticides used by South African forestry were compared for environmental persistence and toxicity (**Table 2**). Three (endosulfan, gamma BHC, chlordane) of the 12 insecticides in this evaluation are chlorinated hydrocarbons and, consequently prohibited from use. A further 5 insecticides (cypermethrin, deltamethrin, cyfluthrin, methiocarb, carbosulfan) rank as unacceptable and become prohibited from use because they exceed the toxicity thresholds. Although acephate is evaluated as marginal it should also be ranked as unacceptable. Three insecticides (*Bacillus thuringiensis* (Bt), diflubenzuron, carbaryl) remain as acceptable for use in certified forests but only Bt is registered for use against emperor moth larvae attacking pines in forestry. Alphacypermethrin falls in the same class of insecticides (synthetic pyrethroid) as deltamethrin and cypermethrin and is probably also unacceptable because of its toxicity (**Table 1**). Toxicity is the innate capacity of a chemical to produce injury or harm whereas hazard is the potential for injury involved in a given situation. Hazard varies according to dose, exposure, toxicity and formulation but toxicity is built into the pesticide (Baker *et al.*, 1995). Hence most of the insecticides that can be judged as acceptable according to the WHO hazard classification system, are disqualified on a toxicity evaluation (**Table 2**). Therefore none of the insecticide treatments (except Bt which is a microbial insecticide), that are available to the forestry industry for use against insect pests can be used in certified plantations. This elimination process, by default, meets the phased reduction of chemical use as a requirement of criterion 6.6. However, only a plan of phased insecticide reduction is, in itself, insufficient for certification unless it explicitly aims at pest management without chemicals (Radosevich *et al.*, 2000). Logistically FSC expects operators to comply with up-to-date guidance for pest and weed management on all sites including nurseries. FSC requires that a programme be developed and implemented to record chemical usage over time and that these trends are regularly analysed. Appropriate application equipment, protective clothing and training on insecticide use needs to be provided, that as a minimum comply with legal requirements. Chemical storage, mixing and application procedures must meet minimum applicable regulations and codes of practice. Operators need to be aware of, and able to, implement emergency procedures for clean-up following spillage or other accidents with chemicals (spill kits must be on site). Records should be kept of all incidents involving chemicals (Qualifor, 2002).

Some certified forests are still using chemical pest control until alternative control measures can be developed. These forest managers are expected to demonstrate that they are carrying out a decision-making procedure for chemical use before application (recording the use of any chemical, the non-chemical alternatives that were considered, the justification for the use of the chemical), and that they monitor their chemical use (McNamara, 2002). In special cases and in situations of environmental emergency, for example, when pest outbreaks cannot be controlled by conventional means, and which threaten the ecological stability of a region, then certain acceptable insecticides may be used (Radosevich *et al.*, 2000).

Table 2. Examples of the FSC status of South African forestry insecticides based on environmental persistence and toxicity

Chemical	WHO classification	Half-Life (days)	ADI (mg/kg/day)	LD_{50} (mg/kg) (rats)	LC_{50} (mg/L) (rainbow trout)	Other Toxicity	FSC Status
Prohibition threshold	**< II**	**> 100**	**< 0,01?**	**< 200**	**< 0,05**		
Cypermethrin	II	4-56	0,05	251-4123	**0,0020-0,0028**	**Carcinogen**	**Unacceptable**
Endosulfan	**Ib**	50	**0,008**	**18-160**	**0,0015**	**Mutagenic**	**Prohibited**
B. thuringiensis var. *kurstaki*	III	120	NA	>10000	Non-toxic	-	Acceptable
Deltamethrin	II	7-14	0,01	**135-5000**	**0,001-0,010**	-	**Unacceptable**
Acephate	III	3-6	**0,005**	866-945	>1000	Organ	Marginal?
Cyfluthrin	II	2-3	?	869-1271	**0,00068**	-	**Unacceptable**
Diflubenzuron	IV	3-4	0,02	>4640	240	Organ	Acceptable?
Carbaryl	II	7-14	0,01	500-850	5-13	-	Acceptable?
Gamma BHC	IV	**450**	**0,008**	**88-190**	**0,0017-0,090**	**Teratogenic mutagenic**	**Prohibited**
Methiocarb	II	?	**0,001**	**20-100**	0,64	?	**Unacceptable**
Chlordane	II	**1460**	**0,0005**	**200-700**	**0,042-0,090**	**Carcinogen**	**Prohibited**
Carbosulfan	IV	**>100**	**0,005**	**185-250**	**0,042**	?	**Unacceptable**

- Source for values: (Nel *et al.*, 1999; Worthing & Walker, 1987; Extension Toxicology Network, 2002; M. Krause, Dept of Agriculture)
- Values in bold illustrate the reason for FSC prohibition

Use of biocontrol agents

Criterion 6.8. "Use of biological control agents shall be documented, minimised, monitored and strictly controlled in accordance with national laws and internationally accepted scientific protocols. Use of genetically modified organisms shall be prohibited."

All the exotic pests of eucalypt plantations (*G. scutellatus, T. tincticollis, P. semipunctata, P. recurva*) and the exotic black pine aphid (*C. cronartii*) in South Africa are currently under successful biological control, with no known adverse effects. FSC requires that if biological control agents are used, that there is an awareness of relevant national and international laws. One assumes that the requirement for minimal use of biological control agents is based on growing concern amongst scientists about the negative impacts of introduced natural enemies (Hamilton, 2000; Howarth, 1991). These concerns include the effect on indigenous endangered species and their extinction, the risk to non-target organisms, in terms of host specificity, permanence, habitat range, genetic plasticity, mutualisms and the economics of documenting and monitoring such activities when biological control agents are used. However, biological control of exotic insect pests has traditionally been a preferred and successful strategy. This criterion severely restricts such an activity and limits the options for control of exotic pests. Biocontrol is generally regarded as irreversible once the natural enemy has established. For example, the introduction of the parasitic nematode (*D. siricidicola*) from Australia to control *S. noctilio* has inadvertently resulted in the introduction of another genotype of the symbiont fungus, *Amylostereum aerolatum*, that is different to the one carried by the wasp. This may account for the limited establishment of the nematode in South Africa but the negative impact of this action cannot be ascertained presently (Wingfield *et al.*, 2001). The proposed introduction of insects to biologically control invasive plantation tree species by groups outside the forest industry therefore also warrants scrutiny against FSC criterion 6.8. FSC requires that no genetically modified organisms are used in management, production or research programmes. In terms of the management of indigenous defoliators, as an example, this precludes the possibility of engineering the Bt gene into susceptible plantation tree species, and further restricts control options.

Criterion 6.9. "The use of exotic species shall be controlled and actively monitored to avoid adverse ecological impacts."

One assumes that this refers to exotic plantation tree species and not insect biocontrol agents. Restrictions on the use of pesticides and biological control agents as a management strategy will severely handicap the sustainable avoidance of such impacts.

Monitoring and assessment

Criterion 8.2. Forest management should include the research and data collection needed to monitor, at a minimum, the following indicators (amongst others): growth rates, regeneration and condition of the forest, composition and observed changes in the flora and fauna.
Criterion 8.4. "The results of monitoring shall be incorporated into the implementation and revision of the management plan."
Criterion 8.5. "While respecting the confidentiality of information, forest managers shall make publicly available a summary of the results of monitoring indicators, including those listed in Criterion 8.2."

FSC consequently requires that yields of all harvested forest products are recorded and that data are collected on growth rates, regeneration and condition of the forest. Data on the composition and observed changes in the flora and fauna and the effectiveness of conservation activities needs to be collected. Data on costs, productivity and efficiency of forest management and records of monitoring activities must be kept. The results of research and monitoring programmes need to be regularly analysed and the results of monitoring ought to be incorporated into periodic revisions of the management plan, policy and procedures. Summaries of monitoring results should be made available to the public.

These criteria and requirements place a great responsibility on individual plantation managers to regularly monitor, assess, act and report on the health of their plantations and the status of at least indicator species of flora and fauna in their conservation areas. Despite the expertise within the forest industry at present, South Africa does not have the specialised human capacity to fulfill such requirements. The current practice is mainly to periodically monitor permanent sampling plots with the help of specialist plant pathologists and entomologists. The fact that most foresters respond to the incidence of insect pests reactively (when damage has already occurred) as opposed to proactively, indicates that monitoring of pests according to economic thresholds is not practiced. In the few instances where monitoring traps and economic thresholds have been developed, for example the wattle mirid, monitoring as part of the management plan has not been implemented. Other constraints are that the impact, economic-injury level and economic damage associated with economic thresholds, for most forestry insect pests are unknown. Many pests are therefore often treated correctively or preventatively on an insurance policy principal. The implementation of a monitoring programme that feeds into a dynamic management plan would require that forestry personnel be given training in this discipline and that they would interact through a coordinated regional and national network.

Management of plantation pests

Criterion 10.4. "The selection of species for planting shall be based on their overall suitability for the site and their appropriateness to the management objectives. ... Exotic species, which shall be used only when their performance is greater than that of native species, shall be carefully monitored to detect unusual mortality, disease or insect outbreaks and adverse ecological impacts."

The success that the South African forest industry has had with the use of exotic tree species is mainly because these trees have been separated from their native insect and pathogen pests. Poor management of existing pests, inadequate quarantine measures and the lack of contingency plans against new pest incursions can negate the advantages that the industry currently derives from planting exotic tree species.

Criterion 10.7. "Measures shall be taken to prevent and minimise outbreaks of pests, diseases, fire and invasive plant introductions. Integrated pest management shall form an essential part of the management plan, with primary reliance on prevention and biological control methods rather than chemical pesticides and fertilisers. Plantation management should make every effort to move away from chemical pesticides and fertilisers, including their use in nurseries. The use of chemicals is also covered in Criteria 6.6 and 6.7."

FSC require that regular plantation staff are given sufficient training to identify health problems in the plantations and, where appropriate, specialist inspectors are used. There should be documented procedures to be followed in the case of observation of any occurrence of a health problem. These requirements compliment those related to monitoring and assessment.

Integrated pest management (IPM) can be visualised as a bridge that needs to be crossed to avoid significant losses to pests. This bridge is composed of a foundation arch (information and techniques), several vertical pillars (management tactics) and a road surface (avoidance of losses) (Pedigo, 1996). The components of the foundation arch are biological information (seasonal cycle, developmental rates, lifecycle, behaviour, population dynamics) and techniques (species identification, rearing, culturing, monitoring, assessment, sampling) to acquire this biological information. The keystone that connects the above two components of the foundation arch is bioeconomics (crop losses, impact, economic injury levels and economic thresholds). The foundation arch of the bridge supports several pillars that represent control measures in insect pest management. The bridge would not be very stable with only one pillar or tactic, so several tactics should be used in combination to avoid losses to pests. FSC promotes integrated pest management in forestry. Some forest entomologists have embraced and supported such an approach (Ohmart 1990), while others have cautioned that pest control techniques should be used outside an IPM framework because of economic and practical constraints, for example, effective monitoring, determination of economic injury levels and low operating budgets (Clarke 1995).

Many of the indigenous insect pests that attack plantation tree species in South Africa appear to have insecticidal remedies, while introduced natural enemies successfully control most of the exotic pests. Despite the effectiveness of these control measures in the short term, their 'single pillar' structure can become unstable and can topple in the future. FSC restricts the use of both insecticides (criterion 6.6) and biological control (criterion 6.8) yet promotes biocontrol in criterion 10.7. Such inconsistencies in the draft FSC principles and criteria need to be addressed. These restrictions place a greater reliance on physical control of pests, cultural practices, plant resistance and to a limited extent genetic control as alternative control methods. These control strategies, although important elements of an IPM programme, then better suit resource limited farmers rather than commercial forestry operations, if chemicals and biological control are excluded.

CONCLUSION

Reliance on insecticidal control measures should be viewed as a short-term solution during this 'grace period', until such time that the FSC rules are more strictly applied and the current insecticidal options become prohibited. New insecticidal treatments that meet the FSC criteria will have to be developed together with guidelines for their use. Regulation of the types of insecticides used in forestry, that are applied as a result of active monitoring programmes with well defined economic thresholds could presently best be described as a goal of forestry rather than a reality. Different control strategies and silvicultural operations would be needed to manage exotic and indigenous insect pests. A coordinated monitoring and assessment of pests has to be developed on a regional and national scale. The adoption of an integrated management approach to control high status pests would contribute to the sustainability of commercial plantations in the future but in many instances lacks the basic biological information needed to develop such a system. The very limited forest entomology capacity in South Africa further complicates the situation.

To restate the title question: management of insect pests - have the goal posts changed with certification? Not only have the goal posts changed, certification dictates that we are playing a different game altogether, which requires many more specialised players if we are to win.

ACKNOWLEDGEMENTS

I am grateful to Lorraine McNamara (Global Forest Products) for providing the various unpublished FSC reports, Mareli Krause (National Department of Agriculture) for discussing and providing the WHO hazard classification of South African forestry insecticides and Professor Clarke Scholtz for commenting on the manuscript.

REFERENCES

BAKER, J. R., BARBOUR, K., BRANDENBURG, R. L., GENTER, M. B., SOUTHERN, P. S., SZUMLAS, D. E., and WALDVOGEL, M., 1995. Pesticide Issues and Information Reference Manual. North Carolina Cooperative Extension Service, North Carolina State University.

BARNES, R. D., JARVIS, R. F., SCHWEPPENHAUSER, M. A., and MULLIN, L. J., 1976. Introduction, spread and control of the pine woolly aphid, *Pineus pini* (L), in Rhodesia. *South African Forestry Journal*, 96, 1-11.

BRUZAS, A., 1983. The pine woolly aphid, *Pineus pini* (Macquart) Adelgidae. *Pests and Diseases of South African Forests and Timber, Pamphlet 273,* 7pp. Department of Environment Affairs. Government Printer, Pretoria.

CLARKE, A. R., 1995. Opinion. Integrated pest management in forestry: some difficulties in pursuing the holy-grail. *Australian Forestry* **58:** 147-150.

DEPARTMENT OF WATER AFFAIRS and FORESTRY., 2000. Report on Commercial Timber Resources and Primary Roundwood Processing in South Africa. **1998/1999**. Pretoria.

EXTENSION TOXICOLOGY NETWORK, 2002. EXTOXNET Pesticide Information Profiles. (http://ace.orst.edu/info/extoxnet/pips/).

GOVENDER, P., 1995. The Pest Status and Chemical Control of Whitegrubs and Cutworms in Forestry in the Natal Midlands. *MSc thesis*, University of Natal, Pietermaritzburg.

HAMILTON, G., 2000. When good bugs turn bad. *New Scientist* **(January)**: 30-33.

HOWARTH, F. G., 1991. Environmental Impacts of Classical Biological Control. *Annual Review of Entomology* **36**: 485-509.

KIRSTEN, J. F., TRIBE, G. D., VAN RENSBURG, N. J., and ATKINSON, P. R., 2000. Insect Pests in South African Forest Plantations. In: *South African Forestry Handbook* **2000**: 221-239. South African Institute of Forestry, Pretoria.

MARCHANT, L. J., 1989. The pine needle aphid, *Eulachnus rileyi* Williams (Homoptera: Aphididae): pest status in Natal, Republic of South Africa. *MSc thesis.* University of Natal, Pietermaritzburg.

MCNAMARA, L., 2002. Did you know about the latest draft of the discussion paper on Chemical Pesticides in Certified Forests?. Global Forest Products. South Africa. *Unpublished Report.*

NEL, A., KRAUSE, M., RAMAUTAR, N., and VAN ZYL, K., 1999. A Guide for the Control of Plant Pests. National Department of Agriculture. South Africa. Thirty Eight Edition.

OHMART, C. P., 1990. Insect pests in intensively-managed eucalypt plantations in Australia: Some thoughts on this challenge to a new era in forest management. *Australian Forestry* **53:** 7-12.

PEDIGO, L. P., 1996. *Entomology and pest management.* Prentice Hall Incorporation, London.

QUALIFOR, 2002. Forest Management Certification: Main Assessment Checklist (South Africa). Quality Forest Management - SGS Forestry. Oxford, United Kingdom. *Unpublished Draft.* (http://www.qualifor.com).

RADOSEVICH, S., LAPPE, M., and ADDLESTONE, B., 2000. Use of Chemical Pesticides in Certified Forests: Clarification of FSC Criteria 6.6, 6.7, and 10.7. FSC - USA. *Unpublished Report.*

SHERRY, S. P., 1971. *The Black Wattle (*Acacia mearnsii *De Wild).* University of Natal Press, Pietermaritzburg.

SYNNOTT, T. J., 2000. Chemical Pesticides in Certified Forests. A Draft Interpretation of the FSC P&C for Discussion and Guidance. FSC - Oaxaca. *Unpublished Report.* (http://www.fscoax.org).

TOOKE, F. G. C., 1928. A Borer Pest of Eucalypts. The Destructive *Phoracantha* Beetle and its Control. *Farming in South Africa - Reprint No.* **79**. Union of South Africa. Department of Agriculture, Pretoria.

TOOKE, F. G. C., 1955. The *Eucalyptus* Snout Beetle, *Gonipterus scutellatus*, Gyll. - a Study of its Ecology and Control by Biological Means. *Department of Agriculture - Entomology Memoirs* **3**. The Government Printers, Pretoria.

TRIBE, G. D., 1990a. Phenology of *Pinus radiata* log colonisation by the pine bark beetle *Hylastes angustatus* (Herbst) (Coleoptera: Scolytidae) in the South-Western Cape Province. *Journal of the Entomological Society of Southern Africa*, 53, 93-100.

TRIBE, G. D., 1990b. Phenology of *Pinus radiata* log colonisation and reproduction by the European bark beetle *Orthotomicus erosus* (Wollaston) (Coleoptera: Scolytidae) in the South-Western Cape Province. *Journal of the Entomological Society of Southern Africa,* 53, 117-126.

TRIBE, G. D., 1995. The woodwasp *Sirex noctilio* Fabricius (Hymenoptera: Siricidae), a pest of *Pinus* species, now established in South Africa. *African Entomology*, 3, 215-217.

TRIBE, G. D., and CILLIE, J. J., 1997. Biology of the Australian Tortoise Beetle *Trachymela tincticollis* (Blackburn) (Chrysomelidae: Chrysomelini: Paropsina), a Defoliator of *Eucalyptus* (Myrtaceae), in South Africa. *African Entomology* **5(1):** 109-123.

VAN RENSBURG, N. J., 1981. A technique for rearing the black pine aphid, *Cinara cronartii* T & P, and some features of its biology (Homoptera: Aphididae). *Journal of the Entomological Society of Southern Africa*, 44, 367-379.

VAN V. WEBB, D., 1974. Forest and timber entomology in the Republic of South Africa. *Department of Agricultural Technical Services - Entomology Memoirs*, 34. The Government Printer, Pretoria.

WEIR, F., 2001. Chemical Pesticides Used in Forestry: First Draft. South Africa. *Unpublished Report.*

WINGFIELD, M. J., SLIPPERS, B., ROUX, J., and WINGFIELD, B. D., 2001. Worldwide Movement of Exotic Forest Fungi, Especially in the Tropics and the Southern Hemisphere. *Bioscience* **51(2)**: 134-140.

WORTHING, C. R., and WALKER, S. B., 1987. The Pesticide Manual. A World Compendium. Eight Edition. British Crop Protection Council, United Kingdom.

CHAPTER 8

Overview of entomological research in the Mediterranean forest ecosystem of South Africa

Govender, P. and Wingfield, M. J. 2002. Overview of entomological research in the Mediterranean forest ecosystems of South Africa. *Proceedings of International Union of Forest Research Organisations Symposium on Entomological Research in Mediterranean Forest Ecosystems.* Rabat, Morocco. 6-10 May 2002. (invited oral presentation and accepted for publication).

ABSTRACT

South Africa has approximately 1.4 million hectares committed to commercial plantation forestry. About 7.3% of this resource occurs in the Mediterranean bio-climatic zone. Exotic pines (especially *P. radiata, P. pinaster* and *P. elliottii*) are predominately grown in this region (about 95%), together with small areas of hardwood species. Three indigenous lepidopteran pests, (*Imbrasia cytherea cytherea, Pachypasa capensis* and *Euproctis terminalis*) regularly defoliate *P. radiata*. All other pine pests are exotic. The pine weevil, *Pissodes nemorensis* damages the root collar region of saplings and causes dieback of the terminal shoots of established trees. The pine woolly aphid, *Pineus boerneri*, stunts tree growth. The bark beetle *Hylastes angustatus* causes sporadic damage, while another exotic bark beetle *Orthotomicus erosus* infests stressed trees and is responsible for vectoring blue stain fungus. The pine wood wasp, *Sirex noctilio*, has entered the country and has rapidly spread within the Mediterranean region, during the past seven years. Biocontrol using the parasitic nematode (*Deladenus siricidicola*) and hymenopteran parasitoids (*Ibalia leucospoides, Megarhyssa nortoni*) on the different life stages of *S. noctilio* is ongoing. Furthermore, monitoring and studies on the associated fungal symbiont (*Amylostereum areolatum*) with *S. noctilio* are areas of active research. Four exotic pests attack *Eucalyptus*. The eucalypt snout beetle, *Gonipterus scutellatus*, a defoliator, is under effective biological control by the egg parasitoid *Anaphes nitens*, but often fails at high altitude sites. The eucalypt tortoise beetle, *Trachymela tincticollis*, another defoliator, is also under effective biological control by an egg parasite (*Enoggera reticulata*). Two longhorn beetles, *Phoracantha semipunctata* and *P. recurva* damage the wood of stressed and recently felled trees. The egg parasitoid, *Avetianella longoi* has been established while several larval

parasitoids (*Syngaster lepidus, Jarra maculipennis, Jarra phoracanthae*) are being evaluated for biological control.

En Afrique du Sud, environ 1,4 millions d'hectares sont en sylviculture; dont environ 7,3 pour cent sont dans un biome méditerranéen. Des pins exotiques (particulièrement *P. radiata*, *P. pinaster* et *P. elliottii*) sont majoritairement plantés (95%), suivi d'autres espèces de bois dur. Trois parasites indigènes de lépidoptère, (*Imbrasia cytherea cytherea, Pachypasa capensis* et *Euproctis terminalis*) défeuillent régulièrement le pin radiata. Tous autres parasites du pin sont exotiques. Le charançon de pin, *Pissodes nemorensis*, endommage le collier des jeunes plants et cause le "dieback" des pousses terminales des arbres établis. L'aphis laineux du pin, *Pineus boerneri*, arrête la croissance des arbres. Le coléoptère d'écorce, *Hylastes angustatus*, endommage sporadiquement, alors que *l'Orthotomicus erosus* est responsable de l'infection par le mycète bleu. La guêpe du bois de pin, *Sirex noctilio*, est entrée dans le pays et s'est rapidement propagée dans la région méditerranéenne durant les sept dernières années. Le biocontrôle utilisant le nématode parasite (*Deladenus siricidicola*) et les hyménoptères supplémentaires (*Ibalia leucospoides, Megarhyssa nortoni*), sur les différentes étapes de la vie du *S. noctilio*, dans la surveillance du microbe pathogène symbiote, sont des domaines de recherche actifs. Quatre parasites exotiques attaquent l'eucalyptus. Le coléoptère défoliateur d'eucalyptus, *Gonipterus scutellatus*, est sous contrôle biologique par les *Anaphes nitens*, parasites des oeufs, mais exige des zones d'altitude élevée. Le coléoptère tortue d'eucalyptus, *Trachymela tincticollis*, un autre défoliateur, est également sous contrôle biologique par un parasite des oeufs (*Enoggera reticulata*). Deux coléoptères à longue corne, *Phoracantha semipunctata* et *P. recurva* endommagent le bois des arbres soumis à un stress ou récemment abattus. L'utilisation du parasite des oeufs, *Avetianella longoi*, est établi, tandis que celle de plusieurs parasites larvaires (*Syngaster lepidus, Jarra maculipennis, Jarra phoracanthae*) sont évaluées.

Key words: Entomology, South Africa, Mediterranean ecosystems, forestry research

INTRODUCTION

The Mediterranean bio-climatic zone of South Africa comprises both the winter and all year rainfall areas of the Southern and Western Cape (Vlok & Van der Merwe, 1999). Commercial plantation forestry in this region covers 102 412 ha, which represents 7.3% of the total 1 401 800 ha under exotic plantation forestry in South Africa (Department of Water Affairs and Forestry, 2000). Pines are the main tree species grown (94.5%), followed by eucalypts (4.4%) and other hardwoods. *Pinus radiata* (58 140 ha), *P. pinaster* (24 717 ha) and *P. elliottii* (11 395 ha) are extensively grown, while smaller areas are planted to *P. patula* (1236 ha), *P. taeda* (206 ha) and other pine species (Department of Water Affairs and Forestry, 2000). Amongst the eucalypts, mainly *Eucalyptus grandis* (80%), *E. lehman, E. globulus, E. camaldulensis, E. gomphocephala* and other species are commercially grown (Cillie, 1983).

Exotic plantation species generally grow faster and better than indigenous trees because of the absence of their native pathogen and insect pests. However, many of these pests have gradually entered the southern tip of South Africa, especially via the port of Cape Town (Tribe, 2000). The close proximity of this port to plantation forests has resulted in population build-up and consequently, pest outbreaks. In the absence of natural enemies, many of these pests have severely damaged plantation trees. Highly successful biological control programmes have been instituted against some of these pests in the Mediterranean forest ecosystem of South Africa, and represents an area of historical and active entomological research. The aim of this paper is to provide a brief overview of these activities.

INSECT PESTS OF PINES

Defoliators

Three indigenous lepidopteran pests, *Imbrasia cytherea cytherea, Pachypasa capensis* and *Euproctis terminalis* regularly defoliate pines. Larvae of the pine tree emperor moth (*I. cytherea cytherea*) sporadically defoliate *P. patula* and *P. radiata* trees from about August to November and thus during the active growth phase. They attack stands in the 3 to 23-year-old age-class (Kirsten *et al.*, 2000). Despite the presence of numerous natural enemies of the eggs and caterpillars, these defoliators can still cause serious damage. Several synthetic pyrethroid insecticides (alpha-cypermethrin, beta-cypermethrin, zeta-cypermethrin, cypermethrin) and the microbial agent *Bacillus thuringiensis* var. *kurstaki* (Bt) are registered for use against *I. cytherea cytherea* in forestry (Nel *et al.*, 2002). Unlike the broad-spectrum synthetic pyrethroid insecticides, Bt is the preferred treatment because it is less damaging to non-target organisms. However, Bt has greater efficacy against younger instar larvae and a careful monitoring programme is required. Although a model has been developed to predict the defoliation threat by the pine tree emperor moth (Geertsema, 1980), timber growers still only detect and react to defoliation when it has progressed beyond 50%.

Larvae of the pine brown-tail moth (*E. terminalis*) and the brown lappet moth (*P. capensis*) can also severely defoliate all ages of pines, especially *P. patula*. These defoliators were reported to cause a loss of 80% in increment growth in the year following defoliation and top dieback if it was a year of low rainfall (Kirsten *et al.*, 2000). These stress factors have, in turn, rendered the trees more susceptible to bark beetle attack. Diflubenzuron, a chitin inhibitor, successfully controlled *E. terminalis* in experiments, but requires further testing before it can be registered (Govender, 1997).

Borers

The Sirex woodwasp (*Sirex noctilio*), which is endemic to Eurasia and North Africa, became established in South Africa in 1994 (Tribe, 1995). It attacks amongst others, *P. radiata*, *P. elliottii*, *P. patula*, *P. pinaster*, *P. taeda* and *P. pinea*. Recent studies on the obligate fungal symbiont, *Amylostereum areolatum*, using DNA based techniques have shown that *S. noctilio* was probably introduced into South Africa from South America (Slippers *et al.*, 2000; 2001).

Sirex noctilio has been successfully managed in Australia through the introduction of the parasitic nematode, *Deladenus siricidicola* and this is augmented by four parasitic wasp species (Bedding, 1984; Taylor, 1976). Infested trees at Tokai Plantation in the south-western Cape were inoculated in 1995 with the virulent Kamona strain of the nematode which was obtained from the Commonwealth Scientific and Industrial Research Organisation of Australia (Tribe, 1995). Parasitism at this site was initially 23%, which then increased to 56% the following year and in 1999 was up to 95% (Tribe, 2000). Despite this success and establishment at Tokai Plantation, *D. siricidicola* has spread very slowly and one requires repeated inoculation of pine trees as the *Sirex* front extends northwards.

Limited numbers of an egg and early larval hymenopteran parasitoid, *Ibalia leucospoides* were introduced and released in 1999. Even lower numbers of the late larval parasitoid, *Megarhyssa nortoni*, which are confined to the thicker lower stump, were imported from Tasmania (ex N. America) and released in 2000 (Tribe, 2000).

Annual monitoring of *Sirex* throughout the western and southern Cape has tracked the dispersal of the wasp from its detection site in Cape Town. Dispersal has followed two routes, 205 km between woodlots of pines to the limit of its host range along the West Coast and 225 km along the southern coast to Riversdal (Tribe, 2000). *Sirex noctilio* has since spread to Knysna along the southeast coast (B. Hurley, University of Pretoria, unpublished). This is an advance of about 190 km in two years, since its last detection during 1998/99. Fear that infected logs from the Cape region could reach southern KwaZulu-Natal and spread northwards to other key pine-growing regions has resulted in the halting of log shipments and movement to the summer rainfall areas (Bedford, 2001). This alert and call for co-operation to restrict the movement of timber from infested areas, has now also drawn attention to the need for more stringent biosecurity measures in South Africa.

The DNA-based studies of Slippers *et al.* (2000; 2001) on *A. areolatum* have shown that the fungus represents a single genotype in South Africa and that this is the same as that in other countries of the Southern Hemisphere. This limited genetic diversity provides strong evidence to suggest that *Sirex* has spread between continents of the Southern Hemisphere, after its initial introduction. Fungal isolates from South Africa and Brazil are the most closely related of all isolates, indicating a common origin of *Sirex* in these two countries.

When *D. siricidicola* was introduced into South Africa, it came together with a strain of *A. areolatum* on which it feeds. Slippers *et al.* (2000; 2001) have shown that this fungal strain has also been released into the nematode environment in South Africa. This represents a genotype of *A. areolatum*, different to that carried by the wasp in South Africa. It has been postulated that this may be linked to poor establishment of the nematode in South Africa (Wingfield *et al.*, 2001).

The pine weevil, *Pissodes nemorensis* is native to North America but occurs throughout the Northern Hemisphere. Its occurrence in South Africa was first reported from the southern Cape in 1942 (Van V. Webb, 1974). Under-bark girdling due to larval feeding on the phloem damages pine trees. This usually occurs in the crown of trees where, especially leaders and the first whorl of branches of healthy *P. radiata* trees, 7 years and older are attacked. The trees become "cluster-topped" causing tree malformation and timber loss. During establishment, fertilised seedlings and cuttings of *P. radiata* are also attacked.

Pissodes nemorensis is active during winter and spring and is an important pest in the Mediterranean region yet a minor pest in the summer rainfall areas (Kirsten *et al.*, 2000). Although insecticide application and pruning of infested leaders is possible on younger trees, these methods of control are expensive and labour intensive. Therefore, the introduction of biological control agents from Europe and the United States of America is being considered.

Current research that has been initiated on *Pissodes* includes the morphological and molecular taxonomy of various species, its biology and distribution in different pine growing regions of South Africa, and an evaluation of resistant and susceptible species of pines. Studies on the possible interaction between *Pissodes* and various pine tree pathogens, for example, the pitch canker pathogen *Fusarium circinatum (teleomorph = Giberella circinata)* (Wingfield *et al.*, 1999) and *Sphaeropsis sapinea* (Swart and Wingfield, 1991; Zwolinski *et al.*, 1995) is being considered. An assessment of the impact of *Pissodes* damage in the Western Cape has also been conducted and is being prepared for publication (Tribe, pers. comm.).

Some pine species, for example, *P. pinaster*, *P. pinea* and *P. halepensis* have become invasive in South Africa. South African and foreign entomologists are currently investigating the possibility of using cone and seed feeding insects to reduce the reproductive potential of these pines. One of the candidate biocontrol agents is *Pissodes validirostris*. Besides many other concerns of the Forestry Industry, an obvious conflict of interest is that possible biocontrol agents for *P. nemorensis* will also attack other *Pissodes* species, including *P. validirostris*. Host specificity, whether for the biocontrol of pines or the control of pest species of *Pissodes* will need to be given greater consideration.

Bark beetles

The pine-bark beetle, *Hylastes angustatus* is of European origin. It is a sporadic pest in the Mediterranean forest ecosystems of South Africa. Studies of the phenology of *Hylastes* on *P. radiata* have shown the highest incidence of insects in September and October, where their activity peaks coincides with distinct climatic conditions, i.e. a mean temperature threshold of about 11.4^{0}C occurring simultaneously with rainfall before flight activity (Tribe, 1990a). Hence the higher pest status of *H. angustatus* is in the summer rainfall areas and outside the Mediterranean region.

Tribe (1992) studied pine-bark beetle colonisation sites on *P. radiata* logs, where *H. angustatus* was found in both the buried (64%) and protruding sections of logs. This study promulgated the use of insecticides to protect pine seedlings from attack. Present recommendations (Atkinson and Govender, 1997) to preventatively treat seedlings at planting with insecticides, conflicts with certification principles and criteria of the Forestry Stewardship Council (FSC). Certified plantations are expected to show a phased reduction of insecticide use until other control measures can be developed. This demonstrates the need for enhanced entomological research, especially biological control of *H. angustatus*. Forest hygiene reduces population levels by denying the beetle breeding sites. The move to broadcast plantation residue rather than burning has apparently increased damage due to *H. angustatus*. But burning commonly results in outbreaks of the root pathogen *Rhizina undulata* (Wingfield and Swart, 1994) and is, furthermore, environmentally undesirable.

Hylastes angustatus was introduced into South Africa with a suite of fungi including various species that cause blue stain of sapwood (Zhou *et al.*, 2001). One of these fungi, *Leptographium serpens* has also been linked to death of *P. radiata* and *P. pinaster* in the Western Cape Province (Wingfield and Knox-Davies, 1980). However, the role of the fungus in tree death remains uncertain (Wingfield *et al.*, 1988).

The European bark beetle, *Orthotomicus erosus* is native to Central and Southern Europe, the Near East (Greece, Turkey, Thrace, Macedonia), the Mediterranean Basin, North Africa, and was first discovered in Stellenbosch in the Western Cape in 1968 (Tribe, 1990b). These beetles are summer active, where the annual peak varies between the months of October and February (Tribe, 1990b) in the Mediterranean forest ecosystems of the south-western Cape. *Orthotomicus erosus* usually colonise the aerial sections of *P. radiata* logs (98%) and are unable to detect buried logs (Tribe, 1992). They are opportunistic after drought and fire. Maintaining forest hygiene and tree vigour helps prevent outbreaks.

A larval parasitoid, *Dendrosoter caenopachoides* was introduced into South Africa from Israel in 1985 for biological control of *O. erosus* (Kfir, 1986; Tribe and Kfir, 2001). Although this parasitoid has become established in those areas where it was released, it has a slow rate of dispersal and mostly attacks *O. erosus* larvae that occur in branches and in thin bark stems (Tribe & Kfir, 2001). Such trees tend to be younger and grow more vigorously and are therefore less susceptible to stress and *O. erosus* attack.

Orthotomicus erosus carries a number of *Ophiostoma* spp. and related fungi (Zhou *et al.*, 2001). The most common of these is *Ophiostoma ips*, which is one of the most common causes of sap stain in insect-infested timber in South Africa. The fungus is also mildly pathogenic and might contribute to insect colonisation of timber (Wingfield and Marasas, 1980).

Hylurgus ligniperda is a minor pine tree pest in South Africa. Although it is present throughout the year, it has a population activity peak in April/May (autumn), which is temporally separated from *H. angustatus* and *O. erosus* (Tribe, 1991). Tribe (1991) suggests that *H. ligniperda* could be a valuable bridging host for introduced biological control agents for the other bark beetle species. *Hylurgus ligniperda* mostly colonises logs that are below soil level (86%) (Tribe, 1992). It also carries *Ophiostoma* spp. (Zhou *et al.*, 2001) but these appear to be relatively non-pathogenic and unimportant.

Sap suckers

The black pine aphid, *Cinara cronartii*, which is indigenous to the eastern United States of America, was detected in South Africa in 1974 (Van Rensburg, 1979). It was initially a serious pest of pines in the summer rainfall region, but is now considered of minor importance since the introduction and establishment of the parasitic wasp, *Pauesia cinaravora* (Van Rensburg, 1981). *Cinara cronartii* has been reported to sporadically cause damage to *P. radiata* in the Mediterranean forest ecosystems. This is especially during drought years where the tops and even whole trees may be killed. Populations of *C. cronartii* are normally controlled biologically by *P. cinaravora*, before extensive damage to trees can be caused.

The pine woolly aphid, *Pineus boerneri* has been recorded in North America, Europe, the Mediterranean, Asia and was discovered in South Africa in 1978 (Bruzas, 1983), 10 years after its simultaneous discovery in Kenya and Zimbabwe (Barnes *et al.*, 1976). This aphid was misidentified for many years as *Pineus pini*. *Pineus boerneri* is a serious pest of pines in the Mediterranean forest ecosystems of South Africa. Damaged trees often remain stunted for life. *Pinus radiata* trees show symptoms of rough bark, multiple branching, few and short thick needles, multiple resin pockets, which cause constriction of the conducting vessels (visible in the annual growth rings) and arrested root development following *P. boerneri* attack (Tribe, pers. comm.). Pine woolly aphid attacks are sporadic though, and seldom occur for more than two to three years in a given area. Although 60% of stunted trees are removed during thinning, the remaining 40% still represent a significant loss (Tribe, pers. comm.). The indigenous ladybird predator *Exochomus flavipes*, sometimes controls *P. boerneri*. While *P. pinaster* is the most attractive of all the pine species in the Western-Cape, and can recover if trees are growing vigorously on favourable sites, *P. radiata* has no resistance to *P. boerneri* and remains permanently stunted after attack (Tribe, pers. comm.).

INSECT PESTS OF EUCALYPTS

Defoliators

The tortoise beetle, *Trachymela tincticollis* is a native of Australia and was first discovered in the Mediterranean forest ecosystem of South Africa in 1982 (Cillie, 1983). It currently remains restricted to this region and despite having dispersed about 1330 km in four years since its detection (Tribe & Cillie, 1997), it has not spread to summer rainfall areas.

The biology and phenology of *T. tincticollis* were intensively studied, as a prerequisite for the implementation of a biological control programme (Tribe & Cillie, 1997). In 1986, the egg parasitoid, *Enoggera reticulata* was imported from South Western Australia and achieved successful parasitism (96%) within a year after its release (Tribe & Cillie, 1997). It is now firmly established as a biocontrol agent in South Africa.

The eucalypt snout beetle, *Gonipterus scutellatus* is also native to Australia and was first discovered in the Mediterranean forest ecosystem of South Africa in 1916 (Mally, 1924). *Eucalyptus globulus, E. viminalis* and *E. maidenii* were the major plantation species grown at the time. Damage by *G. scutellatus* was so severe that these species had to be replaced by the moderately resistant, *E. grandis*.

Gonipterus scutellatus now also occurs throughout the *Eucalyptus* growing area of South Africa. This pest was intensively studied in South Africa and an extensive search for natural enemies in Australia resulted in the introduction of an egg parasitoid, *Anaphes nitens* in 1926 (Tooke, 1942; 1943; 1955). This represents the first example of classical biological control success in South Africa. This control is highly effective but sometimes fails when susceptible eucalypt species are grown at high altitude sites (Richardson & Meakins, 1986). The effect of abiotic factors on the biological control of *G. scutellatus* by *A. nitens*, along altitudinal and temporal gradients is currently being studied. Furthermore, the susceptibility and the effect on secondary leaf metabolites of various cold-tolerant eucalypt species are under investigation.

Wood borers

The eucalypt borers, *Phoracantha semipunctata* and *P. recurva* are indigenous to Australia and were detected in the South African Mediterranean forest ecosystem in 1906 (Tooke, 1928; 1935). They attack freshly cut logs and stressed trees by burrowing under the bark and later boring into the timber. An egg parasitoid, *Avetianella longoi* was collected from Adelaide, Australia and introduced into South Africa in 1993 (Kirsten *et al.* 2000). Although *A. longoi* is established in localised areas of the Mediterranean forest ecosystem, its efficacy has not yet been determined.

Phoracantha recurva tends to colonise branches and smaller diameter trunks. The insect emerges earlier (between October and December) than *P. semipunctata* (December to March), while *A. longoi* is only active between December and March. This appears to be creating a tilt in favour of *P. recurva* (Tribe, unpublished report), hence the focus on larval and pupal parasitoids. The pupal parasitoid, *Megalyra fasciipennis* was recently detected in South Africa and several larval parasitoids (*Jarra phoracantha, J. maculipennis, Syngaster* *lepidus*) were introduced from California; the success of these introductions must still be investigated.

BIOLOGICAL CONTROL OF PLANTATION FORESTRY SPECIES

Various species of *Pinus*, *Eucalyptus* and *Acacia* are reported to have become invasive weeds in the Mediterranean forest ecosystems of South Africa (Henderson, 1999). Reducing the reproductive capacity of these tree species with introduced pests and pathogens is being considered as a possible solution to this problem. Biological control using various seed and fruit infesting insects on various *Acacia* species has already been implemented with substantial success (Dennill *et al.*, 1999; Donnelly, 1995; Donnelly *et al.*, 1992). Possible biological control of invasive *Pinus* species using seed and cone infesting insects is currently being evaluated.

REFERENCES

ATKINSON P.R., GOVENDER P., 1997. Mortality of *Pinus patula* seedlings due to *Hylastes angustatus* (Herbst) (Coleoptera: Scolytidae). *ICFR Bulletin Series, 8/97*. Institute for Commercial Forestry Research, University of Natal, Pietermaritzburg. South Africa.

BARNES R.D., JARVIS R.F., SCHWEPPENHAUSER M.A., MULLIN L.J., 1976. Introduction, spread and control of the pine woolly aphid, *Pineus pini* (L), in Rhodesia. *South African Forestry Journal*, 96, 1-11.

BEDDING R.A., 1984. Nematode parasites of Hymenoptera. *In*: Nickle, W. R. (Ed.) *Plant and Insect Nematodes*. Marcel Dekker Inc., New York, p.755-795.

BEDFORD L., 2001. Wood wasp halts log shipments to summer rainfall regions. *Wood Southern Africa & Timber Times*, December. p.4-6. Malnor (Pty) Ltd, South Africa.

BRUZAS A., 1983. The pine woolly aphid, *Pineus pini* (Macquart) Adelgidae. *Pests and Diseases of South African Forests and Timber, Pamphlet 273*, 7pp. Department of Environment Affairs. Government Printer, Pretoria.

CILLIE J.J., 1983. The *Eucalyptus* tortoise beetle, *Trachymela tincticollis* Blackburn (Chrysomelidae: Coleoptera). *Pests and Diseases of South African Forests and Timber, Pamphlet 273*, 4pp. Department of Environment Affairs. Government Printer, Pretoria.

DENNILL G.B., DONNELLY D., STEWART K., IMPSON F.A.C., 1999. Insect agents used for the biological control of Australian *Acacia* species and *Paraserianthes lophantha* (Willd.) Nielsen (Fabaceae) in South Africa. *African Entomology Memoir*, 1, 45-54.

DEPARTMENT OF WATER AFFAIRS and FORESTRY., 2000. Report on commercial timber resources and roundwood processing in South Africa. 1998/1999. Pretoria.

DONNELLY D., 1995. Good news for blackwood biocontrol. *Plant Protection News*, 41, 4.

DONNELLY, D. CALITZ F.J., VAN AARDE I.M.R., 1992. Insecticidal control of *Melanterius servulus* (Coleoptera: Curculionidae), a potential biocontrol agent of *Paraserianthes lophantha* (Leguminosae), in commercial seed orchards of black wattle, *Acacia mearnsii* (Leguminosae). *Bulletin of Entomological Research*, 82, 197-202.

GEERTSEMA H., 1980. A method of predicting the defoliation threat to pines by the pine tree emperor moth, *Nudaurelia cytherea*, by counting dead moths on the forest floor. *South African Forestry Journal*, 113, 26-29.

GOVENDER P., 1997. Insecticide trial for *Euproctis terminalis* (pine brown tail moth) control: efficacy assessment. *In*: Annual Report of the Institute for Commercial Forestry Research: 102-103. University of Natal, Pietermaritzburg.

HENDERSON L., 1999. The South African plant invaders atlas (SAPIA) and its contribution to biological weed control. *African Entomology Memoir*, 1, 159-163.

KIRSTEN J.F., TRIBE G.D., VAN RENSBURG N.J., ATKINSON P.R., 2000. Insect pests in South African forest plantations. *In*: OWEN, D. L., (Ed). *South African Forestry Handbook 2000* (vol. 1), 221-239. South African Institute of Forestry, Pretoria.

MALLY C.W., 1924. The *Eucalyptus* snout-beetle (*Gonipterus scutellatus*, Gyll.). *Reprint No.* **51**, *from the Journal of the Department of Agriculture*, November, 415-442. The Government Printing and Stationery Office, Pretoria.

NEL A., KRAUSE M., KHELAWANLALL N., 2002. A guide for the control of plant pests. *National Department of Agriculture*. Republic of South Africa. Government Printer, Pretoria.

KFIR R., 1986. Releases of natural enemies against the pine bark beetle *Orthotomicus erosus* (Wollaston) in South Africa. *Journal of the Entomological Society of Southern Africa*, 49, 391-392.

RICHARDSON K.F., MEAKINS R.H., 1986. Inter- and intra-specific variation in the susceptibility of eucalypts to the snout beetle *Gonipterus scutellatus* Gyll. (Coleoptera: Curculionidae). *Suid Afrikaanse Bosboutydskrif*, 139, 21-31.

SLIPPERS B., WINGFIELD M.J., WINGFIELD B.D., COUTINHO T.A., 2000. Relationships among *Amylostereum* species associated with siricid woodwasps inferred from mitochondrial ribosomal DNA sequences. *Mycologia*, 92, 955-963.

SLIPPERS B., WINGFIELD M.J., COUTINHO T.A., WINGFIELD B.D., 2001. Population structure and possible origin of *Amylostereum aerolatum* in South Africa. *Plant Pathology*, 50, 206-210.

SWART W.J., WINGFIELD M.J., 1991. Biology and control of *Sphaeropsis sapinea* on *Pinus* spp in South Africa. *Plant Disease*, 75, 761-766.

TAYLOR K.L., 1976. The introduction and establishment of insect parasitoids to control *Sirex noctilio* in Australia. *Entomophaga*, 21, 429-440.

TOOKE F.G.C., 1928. A borer pest of eucalypts. The destructive *Phoracantha* beetle and its control. *Farming in South Africa - Reprint No.* 79. Union of South Africa. Department of Agriculture, Pretoria.

TOOKE F.G.C., 1935. Die phoracantha-tor (*Phoracantha semipunctata* F.). *In*: Skadelike insekte van bos- en skaduweebome. *Departement van Landbou en Bosbou - Pamflet*, 142, 33-38. Unie van Suid Afrika Staatsdrukker, Pretoria.

TOOKE F.G.C., 1942. The biological control of the *Eucalyptus* snout beetle, *Gonipterus scutellatus*, Gyll. - a summarised report. *Department of Agriculture and Forestry - Science Bulletin No.* 235. Union of South Africa Government Printers, Pretoria.

TOOKE F. G. C., 1943. Progress of Forest Entomology in South Africa. *Journal of the South African Forestry Association* **10:** 4-12.

TOOKE, F.G.C., 1955. The *Eucalyptus* snout beetle, *Gonipterus scutellatus*, Gyll. - a study of its ecology and control by biological means. *Department of Agriculture - Entomology Memoirs* 3. The Government Printers, Pretoria.

TRIBE G.D., 1990a. Phenology of *Pinus radiata* log colonisation by the pine bark beetle *Hylastes angustatus* (Herbst) (Coleoptera: Scolytidae) in the South-Western Cape Province. *Journal of the Entomological Society of Southern Africa*, 53, 93-100.

TRIBE G.D., 1990b. Phenology of *Pinus radiata* log colonisation and reproduction by the European bark beetle *Orthotomicus erosus* (Wollaston) (Coleoptera: Scolytidae) in the South-Western Cape Province. *Journal of the Entomological Society of Southern Africa*, 53, 117-126.

TRIBE G.D., 1991. Phenology of *Pinus radiata* log colonisation by the red-haired pine bark beetle *Hylurgus ligniperda* (Fabricius) (Coleoptera: Scolytidae) in the South-Western Cape Province. *Journal of the Entomological Society of Southern Africa*, 54, 1-7.

TRIBE G.D., 1992. Colonisation sites on *Pinus radiata* logs of the bark beetles, *Orthotomicus erosus, Hylastes angustatus* and *Hylurgus ligniperda* (Coleoptera: Scolytidae). *Journal of the Entomological Society of Southern Africa*, 55, 77-84.

TRIBE G.D., 1995. The woodwasp *Sirex noctilio* Fabricius (Hymenoptera: Siricidae), a pest of *Pinus* species, now established in South Africa. *African Entomology*, 3, 215-217.

TRIBE G.D., 2000. Biological control of *Sirex noctilio* F. in South Africa 1994 - 2000. *Unpublished Report*.

TRIBE G.D., KFIR R., 2001. The establishment of *Dendrosoter caenopachoides* (Hymenoptera: Braconidae) introduced into South Africa for the biological control of *Orthotomicus erosus* (Coleoptera: Scolytidae), with additional notes on *D.* sp. nr. *labdacus*. *African Entomology*, 9, 195-198.

TRIBE G.D., CILLIE J.J., 1997. Biology of the Australian tortoise beetle *Trachymela tincticollis* (Blackburn) (Chrysomelidae: Chrysomelini: Paropsina), a defoliator of *Eucalyptus* (Myrtaceae), in South Africa. *African Entomology*, 5, 109-123.

VAN RENSBURG N.J., 1979. *Cinara cronartii* on the roots of pine trees (Homoptera: Aphididae). *Journal of the Entomological Society of Southern Africa*, 42, 151-152.

VAN RENSBURG N.J., 1981. A technique for rearing the black pine aphid, *Cinara cronartii* T & P, and some features of its biology (Homoptera: Aphididae). *Journal of the Entomological Society of Southern Africa*, 44, 367-379.

VAN V. WEBB D., 1974. Forest and timber entomology in the Republic of South Africa. *Department of Agricultural Technical Services - Entomology Memoirs*, 34. The Government Printer, Pretoria.

VLOK A.C., VAN DER MERWE J.H., (Eds.). 1999. *Kagiso Senior Desk Atlas*. Kagiso Education, Cape Town.

WINGFIELD M.J., KNOX-DAVIES P.S., 1980. Root disease, associated with *Verticicladiella alacris*, of pines in South Africa. *Plant Disease*, 64, 569-571.

WINGFIELD M.J., MARASAS W.F.O., 1980. *Ceratocystis ips* associated with *Orthotomicus erosus* (Coleoptera: Scolytidae) on *Pinus* spp. in the Cape Province of South Africa. *Phytophylactica*, 12, 65-69.

WINGFIELD M.J., SWART W.J., 1994. Integrated management of forest tree diseases in South Africa. *Forest Ecology and Management*, 65, 11-16.

WINGFIELD M.J., CAPRETTI P., MACKENZIE M., 1988. *Leptographium* spp. as root pathogens of conifers. An international perspective. p. 113-128. *In*: Harrington T.C., Cobb Jr. F.W. (Eds.) : *Leptographium root diseases of conifers*. American Phytopathological Society Press. St Paul, Minnesota, USA.

WINGFIELD M.J., WINGFIELD B.D., COUTINHO T.A., VILJOEN A., BRITZ H., STEENKAMP E.T., 1999. Pitch canker: A South African perspective. Proceedings of the IMPACT Monterey Workshop. Monterey, California. *In*: Devey M., Matheson C., Gordon T. (Eds.) : *CSIRO Forestry and Forest Products Technical Report*, 112, 62-69.

WINGFIELD M.J., SLIPPERS B., ROUX J., WINGFIELD B.D., 2001. Worldwide movement of exotic forest fungi, especially in the tropics and the Southern Hemisphere. *BioScience*, 51, 134-140.

ZHOU X., DE BEER Z.W., WINGFIELD B.D., WINGFIELD M.J., 2001. Ophiostomatoid fungi associated with three pine-infesting bark beetles in South Africa. *Sydowia*, 53, 290-300.

ZWOLINSKI J., SWART W.J., WINGFIELD M.J., 1995. Association of *Sphaeropsis sapinea* with insect infestation following hail damage of *Pinus radiata*. *Forest Ecology and Management*, 72, 293-298.