Soil invertebrate pests in the re-establishment of plantations in South Africa

by

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CHAPTER 9

General Summary

Insect pests and pathogens cause significant losses to the South African forestry industry, and they pose one of the greatest threats to its long-term sustainability and productivity. South African forestry has previously taken advantage of exotic planting stocks (*Acacia mearnsii*, *Eucalyptus* spp. and *Pinus* spp.) that were initially free from their natural enemies. This situation has changed with the gradual appearance of accidentally introduced and/or invasive indigenous pests. This trend is likely to continue with the increasing movement of people and products around the world and the expansion of commercial forestry into low productivity and old arable sites. Forest entomology services and research in South Africa have become fragmented and depleted to the extent that capacity in this field has declined in recent years. Yet there is a need for research in areas such as biological and other pest control measures, contingency plans against incursions, the biology and bioeconomics of new pests, and insect-pathogen interactions. A concerted effort is, therefore, required to create capacity and revitalise this important field of science in South Africa.

There is a limited availability of land for the expansion of commercial plantations in South Africa, and this has resulted in a shift from extensive to intensive silviculture. Rather than afforest new areas, existing plantation areas are being regenerated. One of the ways to increase productivity in a given area, besides genetic improvement, is to ensure the survival of seedlings during regeneration, thereby increasing the stocking of compartments. The cyclic nature of plantation forestry results in areas being continually regenerated and considerable silvicultural research has been done to ensure the survival of seedlings during regeneration.

Soil invertebrate pests and pathogens 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 were, prior to the present work, unclear, and in many instances unknown.

Seedlings that failed to establish during wattle regeneration ranged from 8.95% to 50.84%, and the incidence of damage by soil invertebrate pests ranged from 2.15% to 30.21%. In sites where the plantation residue was windrowed and burnt, the average total incidence of soil invertebrate pests was 20.34%, and the average total failure of wattle seedlings to establish was 34.42%. Whitegrubs were the dominant and most economically important soil invertebrate pests (average incidence of 12.52%), followed by cutworms (average incidence of 3.97%) and grasshoppers (average incidence of 2.12%). Other soil invertebrate pests included termites, tipulid larvae, false wireworms, crickets, millipedes, ants and nematodes. Nematodes were sporadically important (11.58%) in old arable wattle sites.

Little was previously known about the incidence of soil invertebrate pests and diseases in low and high productivity coastal and inland regenerated eucalypt sites. 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 that in 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 low 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.

Soil invertebrate pests encountered during the regeneration of pine included whitegrubs, cutworms, the root feeding bark beetle (*Hylastes angustatus*), grasshoppers and termites. They generally caused low damage (up to 9.51%), except when pines were grown in close proximity to wattle plantations, 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%, which strongly deviated from earlier perceptions of its importance because the causes of high mortality in *P. patula* seedlings were ascribed to abiotic factors and site-species matching rather than *H. angustatus* damage. The inferred role of *H. angustatus*, as a vector of fungal pathogens during the regeneration of pine seedlings has further elevated its pest status.

The effect of different plantation residue management practices on the incidence of soil invertebrate pests was previously unknown. During the regeneration of wattle seedlings, a high incidence of cutworm damage was observed in the windrowed-burnt-ripped and fallow sites. There was a greater infestation of soil invertebrate pests on sites where the plantation residue was windrowed-burnt-weeded or 'broadcast' (20.34%) than in the other treatments [windrowed-burnt-ripped or fallow (mowed, manually weeded) 2.36%]. Similarly 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%. Windrowing and burning of the plantation residue is standard management practice in some pine production areas, and these results warrant a shift to the broadcasting of plantation residue.

The addition of a rip treatment to a depth exceeding 50 cm in the windrowed and burnt regime significantly reduced the infestation of soil invertebrate pests, especially whitegrubs, during wattle regeneration. Seedlings that were planted at a closer spacing in windrowed and burnt sites also had a lower incidence of soil invertebrate pest damage (7.79%). This has important management implications because windrowing and burning are standard plantation residue management practices, in wattle silviculture. Pursuit of sustainable silviculture warrants a move away from the burning of windrows (hot burns) to cool burns or the broadcasting of plantation residue. Planting in wattle and eucalypt sites is facilitated by the use of a tractor operated 'coulter ripper', which consists of a hydraulic cutting wheel and ripping tine on terrain with slopes of up to 40%. Planting in pine sites is facilitated by the use of a chopper roller after the plantation residue has been broadcast. Insecticide application is the alternative option.

The dominant soil invertebrate pest of wattle. eucalypts and pines is whitegrubs. Besides the effect of ripping during the regeneration of wattle. plantation residue management does not appear to affect the incidence of whitegrub damage. Whitegrub larvae are polyphagous and their distribution is related to the presence of host trees (pine. wattle) of the adult. This. therefore. necessitates the prophylactic application of an insecticide at planting in high risk areas. Such examples are where eucalypts are grown in close proximity to wattle. sugarcane and sometimes pine plantations. or when seedlings are regenerated late in the planting season. or during the regeneration of wattle and sometimes pines. Although the prophylactic application of an insecticide at planting is routinely practiced in some pine regions with the objective to control *H. angustatus*. its use is unwarranted. The routine use of insecticides in certified plantations is. furthermore restricted by Forest Stewardship Council (FSC) guidelines. Application for the relaxation of these rules are necessary in the case of whitegrub control in high risk areas until alternative control measures can be developed.

The certification of commercial forestry according to the 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 twelve or so insecticides currently used in forestry in South Africa. The use of biological control agents needs to be monitored and documented. but their future use. as a control measure needs to be minimised to avoid unanticipated side-effects. The general flora and fauna. and especially insect pest species must be regularly monitored and the results incorporated into an ongoing management plan. 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's management plan for the control of insect pests would certainly contribute to the sustainability of commercial plantations in future. it poses many challenges in the short term. For example. indigenous soil invertebrate pests during seedling regeneration can presently only be controlled with insecticides because of the polyphagous nature of the dominant pest.

South Africa has approximately 1.4 million hectares committed to commercial plantation forestry, which, besides soil invertebrate pests and pathogens, is also attacked by many post establishment pests. Three indigenous lepidopteran pests, (*Imbrasia cytherea cytherea, Pachypasa capensis* and *Euproctis terminalis*) regularly defoliate pine trees. 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 exotic bark beetle *Orthotomicus erosus* infests stressed pine trees and is responsible for vectoring blue stain fungus. The pine wood wasp, *Sirex noctilio*, was introduced into the country and rapidly spread within the Mediterranean region, before invading the southern section of the summer rainfall area. 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.

CHAPTER 1

General Introduction

Commercial plantation forestry competes with agricultural crops for the limited arable land in South Africa (Vlok & Van der Merwe 1999), especially since the lapse of its expansion phase. Over the past decade, most of the land that is available for new afforestation was in low productivity sites (Burley *et al.* 1989). The tree species selected for planting were often not suited to these sites because of incomplete site-species interaction studies (Darrow 1994) or the tree species were susceptible to insect pest and disease attacks. To maximize yields in a limited area, there has also been a corresponding shift from extensive to intensive silviculture of seedlings (Schönau 1990). This increase in plantation productivity is, however, dependent on the initial stocking of trees within compartments. It therefore became important to ensure the protection and survival of seedlings during the establishment and regeneration of sites, which created a renewed emphasis on plantation establishment.

Problem statement

During the initiation of this study, a variable value of up to about 42% failure of various species of forestry seedlings to establish in South Africa was recorded (Rusk *et al.* 1992, 1993, 1994). The causes of this mortality were vaguely known and the impact of soil invertebrate pests and diseases were poorly understood. Various silvicultural attempts to address this problem focussed on the use of improved genetic material, site preparation and cultivation, weed management, nutrition responses, and site-species matching studies. Although these inputs considerably improved the growth of seedlings, they did not always ensure the survival of seedlings. Entomological research on the problems of establishment was a low priority because of the reliance on the corrective use of insecticides. The probability of soil invertebrate pests attacking different species of seedlings was based on previous experience with wattle seedlings (Sherry 1971). Knowledge of the effects of different plantation residue management regimes on the incidence of soil invertebrate pests was also lacking. High-risk areas could not be accurately identified, which precluded strategic planning and budgeting for control measures in the planting programmes. Foresters often replanted dead seedlings with no corrective action, until they experienced repeated failure of seedlings to establish. In some plantation areas of South Africa, the preventative use of insecticides at planting as an insurance against soil invertebrate pest damage was adopted. Besides being financially wasteful and environmentally hazardous, many certified forests were in contravention of certification guidelines.

Study objectives

1. To present a case for the revival of Forest Entomology research in South Africa and to prioritise the entomological research needs of the forestry industry.
2. To assess the status, and to quantify the impact of soil invertebrate pests and any other mortality factors that were responsible for the loss of establishment of regenerated wattle, eucalypt and pine seedlings.
3. To determine the effects of plantation residue management practices on the incidence of soil invertebrate pests.
4. To provide an overview and to consolidate previous research on soil invertebrate pests, some of which appeared in miscellaneous reports.
5. To evaluate current management strategies for forestry pests against the principles and criteria of the Forest Stewardship Council.

Selection of trial sites

Plantation forestry occurs in 13 different geographical zones in South Africa (Department of Water Affairs and Forestry, 1991) (Figure 1). Zones one to four are in the Transvaal and Free State regions, while zones five to nine are in the KwaZulu-Natal regions, and all these zones collectively make up the summer rainfall region of South Africa. Zones 10 to 13 are in the Cape and represent the winter and all year rainfall regions. Experimental trials were conducted only in the summer rainfall region for logistical reasons.

Trial sites and the species of trees that were included in the trial series were selected according to the percentage distribution of commercial plantation areas and tree species within the different zones. Those plantation areas and associated tree species in these zones that had a distribution of about 10% or more of the total distribution of commercial plantation area or tree species (numbers in bold in Table 1), were initially selected for the placement of

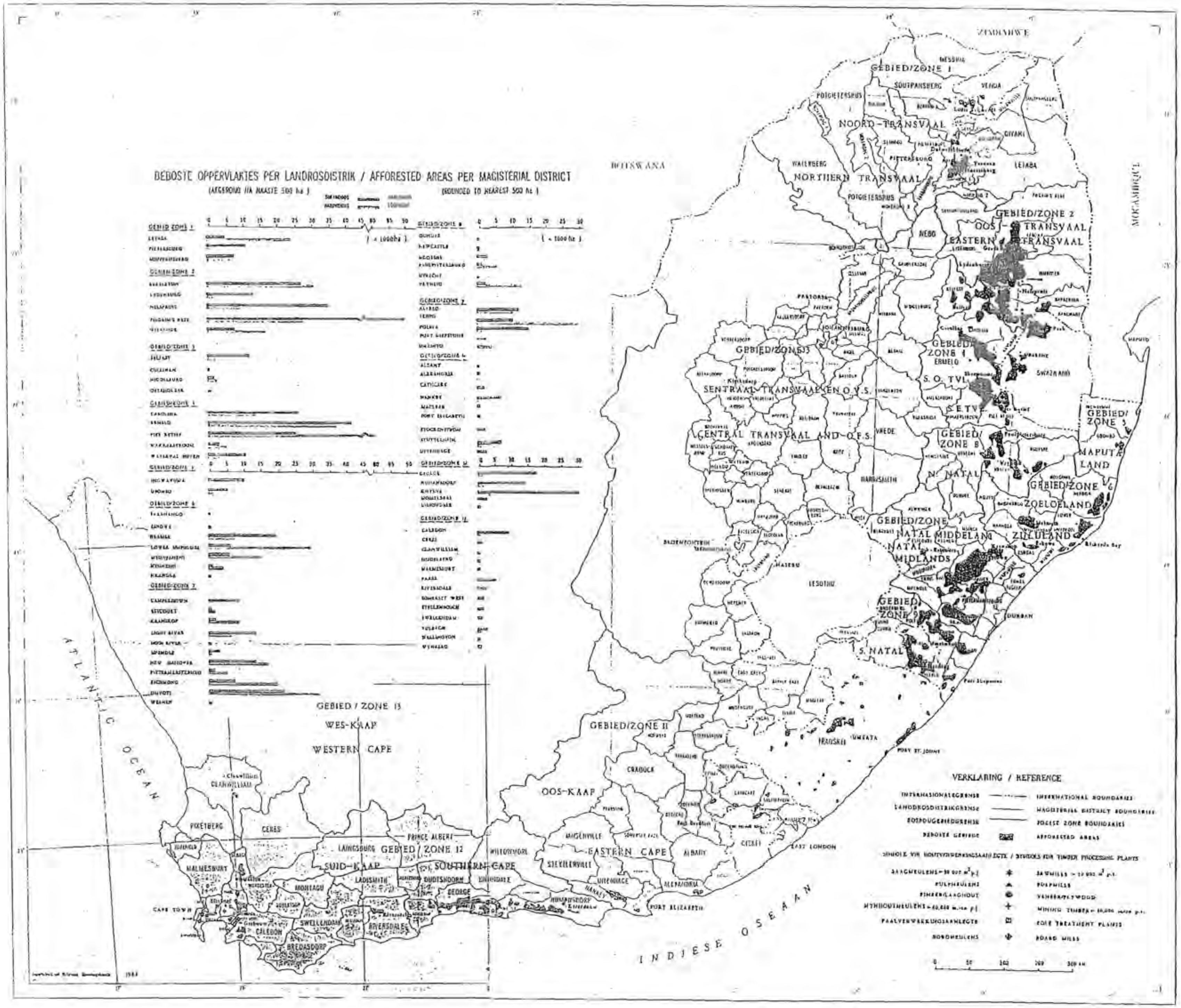

Figure 1. Economic map and regional zones of commercial forestry in South Africa.

Table 1. A comparison of the percentage distribution of commercial forestry plantation species according to economic zones in South Africa over two growing seasons (1995/96 and 1998/99) (extracted from Department of Water Affairs and Forestry 1997, 2000). Predominant areas and species are in bold.

ZONES	Percentage distribution of commercial plantation areas and tree species							
	All plantation tree species		Pines		Eucalypts		Wattle	
	1995/96	1998/99	1995/96	1998/99	1995/96	1998/99	1995/96	1998/99
Summer rainfall areas								
Zone 1 Northern Province	4.2	4.4	3.7	3.9	5.5	5.7	0.1	0.1
Zone 2 Mpumalanga North	**19.5**	**17.6**	**23.5**	**22.0**	**17.6**	**15.5**	0.2	0.0
Zone 3 Central Districts	0.9	1.4	1.2	2.2	0.8	0.6	0.1	0.1
Zone 4 Mpumalanga South	**20.9**	**20.7**	**17.1**	**17.8**	**25.2**	**24.7**	**25.8**	**19.6**
Subtotal	*45.5*	*44.1*	*45.5*	*46.0*	*49.1*	*46.6*	*26.2*	*19.8*
Zone 5 Maputaland	1.2	1.5	1.4	1.3	1.3	1.9	0	0
Zone 6 Zululand	**9.2**	**9.9**	5.4	4.3	**15**	**17.9**	4.1	5.6
Zone 7 Natal Midlands	**14.2**	**13.4**	**11.4**	**9.9**	**13.2**	**12.0**	**40.8**	**42.6**
Zone 8 Northern KZN	5.5	5.8	1.9	2.3	8.3	7.6	**17**	**20.2**
Zone 9 Southern KZN	7.4	8.2	6.1	6.5	8.9	10.2	9.3	9.2
Subtotal	*37.5*	*38.8*	*26.2*	*24.5*	*46.7*	*49.5*	*71.2*	*77.7*
Zone 10	has become invalid							
Zone 11 Eastern Cape	9.9	9.8	15.7	16.2	3.2	3.1	2.4	2.3
All year rainfall areas								
Zone 12 Southern Cape	5.3	5.3	9.3	9.7	0.8	0.6	0.2	0.2
Winter rainfall areas								
Zone 13 Western Cape	1.8	2.0	3.3	3.7	0.2	0.2	0.0	0.0
Subtotal	*17.0*	*17.1*	*28.3*	*29.6*	*4.2*	*3.9*	*2.6*	*2.5*
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

trials. The selection of trial sites was then further refined according to site availability because of the cyclic nature of plantation forestry, previous crop and type of plantation residue management regime. Low versus high productivity plantation area was also screened for the placement of trials to ensure representation.

The percentage distribution of the commercial plantation area per zone and tree species per zone in South Africa were found to be more or less constant when compared during the second (1995/96) and third (1998/99) stages of the trial series (Table 1). This reduced the possibility of deviation from the long-term study objectives or any significant variation in site selection during the study. Zones one to four, five to nine (KwaZulu-Natal) and 11 to 13 (Cape) constituted about 45%, 38% and 17% of the total South African forestry area, respectively (Department of Water Affairs and Forestry 1991). Zones two (Mpumalanga North), four (Mpumalanga South), six (Zululand), seven (Natal Midlands) and eight (Northern KwaZulu-Natal) were therefore selected for the planting of trials. Although the initial study included many tree species in each trial (to test the effects of tree species conversions), only trial sites re-established to the same tree species were considered in this study.

Research Methodology

The trials were conducted in three stages:

1. Ten trials that simultaneously investigated the chemical control of whitegrubs and cutworms (Govender 1995) and the mortality factors influencing the establishment of commercial eucalypt and wattle seedlings, were planted over three growing seasons (1990/91 to 1992/93). The trials were planted in ex-wattle sites, some with different plantation residue management regimes, predominantly in the Natal Midlands (zone 7) and Mpumalanga South (zone 4), these regions representing about 41% and 26% of all the wattle plantations in South Africa respectively (Table 2). These trials were either a complete randomised block design or latin square design with five or six replicates. Seedlings were planted in split plots of treated and untreated seedlings, surrounded by untreated guard row seedlings. During the first year of growth, trials were assessed at monthly intervals after planting. Stressed, dead or dying seedlings were dug and the roots and surrounding soil were examined to determine the cause of death. A description of the

Table 2. Details of site characteristics, species of seedlings planted, and plantation residue management of the three trial series in the study. (MAT: mean annual temperature, MAP: mean annual precipitation).

Trial code	Month planted	Region	Previous species	Zone	Plantation residue management	Latitude	Longitude	MAT (°C)	Altitude (m)	MAP (mm)	Plantation seedling species planted				
WG1	October-90	Seven Oaks	wattle	Z 7	windrow, burnt	29° 12' S	30° 38' E	16.9	1110	837	wattle	*E. grandis*			
WG2	December-90	Umvoti	wattle	Z 7	windrow, burnt, ripped	29° 11' S	30° 27' E	15.8	820	774	wattle	*E. grandis*			
WG3	December-90	Melmoth	wattle	Z 6	windrow, burnt, close spacing	28° 31' S	31° 17' E	17.0	1050	972	wattle	*E. grandis*			
WG4	January-91	Pietermaritzburg	wattle	Z 7	windrow, burnt	29° 32' S	30° 27' E	17.0	930	875	wattle	*E. grandis*			
WG5	February-91	Richmond	wattle	Z 7	fallow, mowed	29° 49' S	30° 17' E	17.0	1020	1019	wattle	*E. grandis*			
WG6	March-91	Hilton	wattle	Z 7	fallow, manually weeded	29° 34' S	30° 16' E	16.0	1165	1111	wattle	*E. grandis*			
WG7	December-91	Seven Oaks	wattle	Z 7	windrow, burnt, close spacing	29° 11' S	30° 40' E	17.1	1110	754	wattle	*E. grandis*			
WG8	January-92	Pietermaritzburg	wattle	Z 7	windrow, burnt	29° 33' S	30° 27' E	17.6	840	990	wattle	*E. grandis*			
WG9	October-92	Pietermaritzburg	wattle	Z 7	windrow, burnt	29° 33' S	30° 27' E	17.6	900	990	wattle	*E. grandis*			
WG10	October-92	Seven Oaks	wattle	Z 7	windrow, burnt	29° 10' S	30° 39' E	18.6	1020	708	wattle	*E. grandis*			
ESPD1	November-95	Bulwer	pine	Z 7	completely burnt	29° 36' S	30° 08' E	15.2	1440	918	wattle	*E. grandis*	*E. mac*	*P. patula*	*P. elliottii*
ESPD2	December-95	Pietermaritzburg	eucalypts	Z 7	windrow, burnt	29° 32' S	30° 27' E	17.9	866	889	wattle	*E. grandis*	*E. dunnii*	*P. patula*	*P. elliottii*
ESPD3	February-96	Pietermaritzburg	wattle	Z 7	windrow, burnt	29° 32' S	30° 28' E	17.9	850	897	wattle	*E. grandis*	*E. dunnii*	*P. patula*	*P. elliottii*
ESPD4	November-96	Howick	eucalypts	Z 7	windrow, no burn	29° 27' S	30° 13' E	16.8	1100	961	wattle	*E. grandis*	*E. mac*	*P. patula*	*P. elliottii*
ESPD5	February-97	Iswepe	wattle	Z 4	broadcast, herbicide	26° 48' S	30° 37' E	16.1	1470	800	wattle	*E. grandis*	*E. mac*	*P. patula*	*P. elliottii*
ESPD6	February-97	Iswepe	wattle	Z 4	windrow, burnt	26° 48' S	30° 37' E	16.1	1470	800	wattle	*E. grandis*	*E. mac*	*P. patula*	*P. elliottii*
ESPD7	March-97	Sabie	pine - fallow	Z 2	fallow, herbicide	25° 06' S	30° 46' E	17.3	1140	1222	wattle	*E. grandis*	GU	*P. patula*	*P. elliottii*
ESPD8	September-97	KwaMbonambi	eucalypts	Z 6	broadcast	28° 36' S	30° 06' E	21.6	50	1065	GU170	*E. grandis*	ZG40	TAG53	GC747
ESPD9	October-97	Elandsdrift	pine	Z 2	broadcast, chopper rolled	25° 12' S	30° 48' E	16.8	1320	1290	*Grandis CSO*	*E. grandis*	*P. gregii*	*P. patula*	*P. elliottii*
ESPD10	July-98	Nylalazi	eucalypts	Z 6	broadcast	28° 03' S	32° 24' E	21.9	37	852	GU7	*E. grandis*	GC SZ14	GC SZ17	GC SZ11
ESPD11	April-00	Wakkerstroom	wattle	Z 4	windrow, burnt	27° 21' S	30° 38' E	17.8	1197	897	wattle	*E. grandis*	*E. dunnii*	*E. mac*	GXN121
ESPD12	April-00	Piet Retief	pine	Z 4	windrow, burnt	26° 56' S	30° 33' E	16.2	1433	882	GPVM	*E. mac*	*E. dunnii*	*P. patula*	*P. elliottii*

symptomatic damage was also recorded. These trials were observational and were backed by responses or a lack thereof to insecticidal treatments. Mortality of the untreated seedlings was expressed as a percentage loss of establishment.

2. Seven trials were planted over two seasons (1995/96 to 1996/97) to determine the mortality factors influencing the establishment of commercial pine, eucalypt and wattle seedlings (Table 2). These trials were planted in both low and high productivity, ex-wattle, ex-eucalypt and ex-pine sites with different plantation residue management regimes. Zones two, four and seven were targeted as representative of the major areas of forestry. Trials were a complete randomised block design with five treatments (seedling species) per replicate (four). There were no insecticide treatments and the treatment plots were large (100 seedlings per plot). Causes of seedling mortality were assessed at monthly intervals after planting, and the cause of death was determined in a similar manner (observational and symptomatic) as the stage one trials.

3. Five trials over three seasons (1997/98 to 1999/00) were planted to cover the remaining representative sites, tree species and plantation residue management regimes (Table 2). The trial design was expanded to a five by five latin square, with five species of trees but each plot comprised 120 trees. Each plot was divided into five subplots of 24 trees. Each subplot was treated with either an insecticide, a fungicide, or a mixture of this insecticide and fungicide and two subplots were untreated. The response of these treatments compared to untreated plots was used to test the accuracy of the observational method above and shed light on the cause of death in cases where a diagnosis could not be made. Surveys and evaluations were conducted in a similar manner as before.

Thesis structure

There has been much erosion of Forest Entomology capacity in South Africa and a case to revive this important discipline is presented in Chapter 2. The need for research on soil invertebrate pests that affect the establishment of seedlings/saplings of all three exotic plantation species is also highlighted. Chapter 3 assesses the impact and status of soil invertebrate pests that affect the regeneration of wattle seedlings and presents an overview of previous research on the biology of these pests. The effect of deviations from the commonly practiced windrow and burn regime of plantation residue management on soil invertebrate pests of wattle regeneration is discussed in Chapter 4. Although all the major eucalypt production areas in South Africa were not surveyed, soil invertebrate pests affecting eucalypt regeneration in both low and high productivity areas of zones six and seven are presented in Chapter 5. The management of pine plantation residue varies in the different pine production zones of South Africa and its effect on soil invertebrate pests and diseases of pine regeneration is investigated in Chapter 6. Chemical control is the first line of defense against many pests that attack plantation forestry in South Africa. However, the majority of commercial growers have opted to certify their plantations according to the Forest Stewardship Council (FSC) guidelines, and the implications of FSC principles and criteria on the management of these pests is assessed in Chapter 7. For the sake of completeness, an overview of entomological research in the winter rainfall region is presented in Chapter 8.

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CHAPTER 2

Forest Entomology in South Africa: current status and future prospects

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ABSTRACT

Insect pests impart significant losses to the South African forestry industry. Together with pathogens, they pose one of the greatest threats to its long-term sustainability. South African forestry has previously gained advantage from the use of an exotic planting stock that was, as a result, initially free from its natural enemies. This situation is changing with the gradual appearance of accidentally introduced new and damaging pests. This trend is likely to continue with the increasing movement of people and products around the world. South African forestry also faces the prospect of the introduction of pests and pathogens for the biological control of those plantation species that have become invasive. Forest entomology services and research in South Africa have become fragmented and depleted and capacity in this field has dwindled in recent years. Yet there is a need for research in areas such as biological, and other, pest control measures; contingency plans against incursions; the biology and bioeconomics of new pests and insect-pathogen interactions. A concerted effort is, therefore, required to create capacity and revitalise this important field of science in South Africa.

INTRODUCTION

The total forest area in South Africa is estimated to be about 2,19 million hectares (Fairbanks *et al.*, 2000), of which the area occupied by commercial forestry plantations is about 1,43 million hectares (Department of Water Affairs and Forestry, 1996). Only one eighth of South Africa is considered arable (Vlok and Van der Merwe, 1999) and about 12,2 % is cultivated (Fairbanks *et al.*, 2000). Commercial forestry plantations occupy about 1,2 % of the total land area of South

Africa (122,3 million ha) (Department of Water Affairs and Forestry, 1996), and there is little room for expansion. It is thus essential to ensure maximum productivity of plantations.

Since their first establishment in South Africa, plantations of pine, eucalypts and wattle have been severely damaged by insect pests. Early in the history of plantation development, beginning with wattle in 1884 (Hepburn 1973), native insects such as defoliating Lepidoptera [*Chaliopsis junodi* (wattle bagworm) (Hardenberg, 1919; Hepburn, 1973; Naude *et al.*, 1939; Ossowski, 1956, 1958; Ripley *et al.*, 1934, 1936; Sherry and Ossowski, 1967), *Imbrasia cytherea* (pine emperor moth) (Tooke, 1935a; Tooke and Hubbard, 1941), *Euproctis terminalis* (pine brown tail moth) (Grobler, 1956; Tooke, 1935b, 1938) and *Pachypasa capensis* (pine lappet moth) (Du Toit, 1975a; Tooke, 1943; Van Dyk, 1969)] imparted significant loss and necessitated extensive and costly insecticidal applications.

Fortunately, only a few of the potential pests of locally grown exotic trees have been accidentally introduced into South Africa. None the less, many of these have resulted in serious damage. For example, the early arrival of the Eucalypt snout beetle (*Gonipterus scutellatus*) caused sufficiently serious damage to prompt the initiation of one of the earliest programmes for biological control of a forest pest (Mally, 1924; Tooke, 1942, 1955) (Table1). Many other introduced pests, such as the black pine aphid (*Cinara cronartii*) (Van Rensburg, 1979, 1981), the pine wooly aphid (*Pineus boerneri*) (Barnes *et al.*, 1976), the root feeding bark beetle (*Hylastes angustatus*) (Bevan and Jones, 1971; Du Toit, 1975b; Tribe, 1990), the eucalypt borers (*Phorocantha semipunctata, Phoracantha recurva*) (Tooke, 1928, 1935c) and the very recently introduced pine wood wasp (*Sirex noctilio*) (Tribe, 1995) have a serious impact on South African forestry. They are likely to continue to do so in the future.

THE CURRENT STATUS OF FOREST ENTOMOLOGY

Exotic pests

A large number of herbivore insects that are able to cause severe damage, occur on pine, eucalypts and wattle in their areas of origin (Cibrián-Tovar *et al.*, 1995; CSIRO, 1970; Davidson and Prentice, 1967; Syme, 1990). It would be naïve to believe that many of these pests can be prevented from entering South Africa in the future. There is good evidence to show that there has been a gradually increase in new forest pests and pathogens entering South Africa (Table 1), despite considerable quarantine efforts to prevent accidental introductions.

Quarantine measures

Even in countries such as New Zealand, Great Britain and the United States of America, with enviable quarantine services, introduced pests and diseases of pine and eucalypts are being discovered (Evans, 1997; Haack and Cavey, 1997; Haack *et al.*, 1997; Potter, 1997). There has been increased movement of people and products into South Africa because of the lifting of trade sanctions and the promotion of tourism in recent years. Other countries in Africa, particularly those south of the Sahara, have less efficient quarantine systems than those in South Africa. This weakens most quarantine measures that will be effected or that are in place in South Africa. These factors increase the risk of quarantine failures in the future.

The recent accidental introduction of two of the most serious pests of plantation and urban ornamental trees into countries, despite their outstanding quarantine, illustrates the fact that even the best quarantine measures can fail. One of these pests, the Asian longhorn beetle (*Anoplophora glabripennis*) appeared in North America for the first time in 1996 on urban maple (*Acer*), poplar (*Populus*) and willow (*Salix*) trees. The costs and impact associated with this introduction are already huge (Haack *et al.*, 1997). Likewise, the appearance of one of the most serious pests, the insect-vectored pine wood nematode (*Bursaphelenchus xylophilus*) in Portugal during the latter part of 1999, is already raising significant concerns for the future of native pines throughout Europe (Sousa *et al.*, 2001). Strategies to contain this introduction are being implemented, but based on past experience (Dwinell and Nickle, 1989; Kinn, 1986; Kobayashi, 1981), there is little hope that this species will be eradicated.

Table 1. Approximate dates of discovery of important insect pests on plantation trees species in South Africa.

Introduced Pest	**Year**	**Reference**
Phoracantha semipunctata (phoracantha beetles) (Coleoptera: Cerambycidae)	1906	(Tooke 1928)
Gonipterus scutellatus (eucalypt snout beetle) (Coleoptera: Curculionidae)	1916	(Mally 1924)
Hylastes angustatus (pine bark beetle) (Coleoptera: Scolytidae)	1930	(Bevan & Jones 1971)
Hylotrupes bajulus (pine longhorn beetle) (Coleoptera: Cerambycidae)	1935	(Tooke & Scott 1944)
Pissodes nemorensis (pine weevil) (Coleoptera: Curculionidae)	1942	(Van V. Webb 1974)
Orthotomicus erosus (European bark beetle) (Coleoptera: Scolytidae)	1968	(Geertsema 1979)
Cinara cronartii (black pine aphid) (Hemiptera: Aphididae)	1974	(Van Rensburg 1979)
Pineus boerneri (pine woolly aphid) (Hemiptera: Adelgidae)	1978	(Barnes *et al.* 1976)
Eulachnus rileyi (pine needle aphid) (Hemiptera: Aphididae)	1980	(Katerere 1984)
Trachymela tincticolis (eucalypt tortoise beetle) (Coleoptera: Chrysomelidae)	1982	(Tribe & Cillie 1997)
Cinara cupressi (cypress aphid) (Hemiptera: Aphididae)	1992	
Sirex noctilio (pine wood wasp) (Hymenoptera: Siricidae)	1993	(Taylor 1962; Tribe 1995)

Every effort must be made to exclude forest pests and pathogens from entering South Africa. There has also been an increase in indigenous insects adopting exotic plantation species as hosts over time. A total of 329 species of invertebrates, especially insects, spiders and mites, have been recorded as being associated with wattle trees in South Africa (Hepburn, 1966), 221 species of which are listed as being phytophagous on wattle (Swain and Prinsloo, 1986). Strategies to minimise losses once introductions or infestations have occurred, must also be a critically important component of the long-term security of the local forestry industry. Failure to recognise this will unquestionably lead to lack of future sustainability.

Biological control of plantation trees that have become weeds

Some species of *Pinus*, *Eucalyptus* and *Acacia* disperse from plantations, seedlings establish on roadsides and in other areas of disturbed as well as natural habitats. There are various examples of this happening in South Africa (Henderson, 1999). As part of the Working for Water Programme, *Acacia mearnsii* was estimated to have become invasive in about 2,5 million hectares (widespread, except in arid areas) and *Pinus* species in about 3 million hectares of various biomes (mountain catchments, forest fringes, grasslands and fynbos). This represents 38% of the area invaded by weeds in South Africa (unpublished Working for Water brochure, 1999). The invasive weeds label of plantation forestry species, the liability and responsibility for its eradication when it becomes an invasive weed outside forestry areas, and the new Water Act (Act 36 of 1998), which only recognises plantation forestry, as a "streamflow reduction activity" is a controversial issue between the forest industry, government and environmental groups. The resolution of these issues requires a multidisciplinary research focus.

One of the perceived solutions to the invasive weed problem is to introduce pests and pathogens as biological control agents that would potentially reduce the reproductive capacity of problematic plantation tree species (Zimmerman and Neser, 1999). A recent example is the seed-feeding weevil, *Melanterius maculatus*, that was released for the biological control of *A. mearnsii* (Dennill *et al.*, 1999; Donnelly, 1995; Donnelly *et al.*, 1992). While the South African forestry industry supports environmental preservation, it must remain concerned about any strategy that might threaten its existence (M.B.P. Edwards, personal communication, 2001).

Plant health risk assessment studies are, therefore, necessary before the release of any biological control agents for commercial forestry species. This is currently limited to host specificity studies in quarantine laboratories, which is often restricted by the choice of tree species and the lack of interaction of other biotic factors, for example, pathogens.

Research capacity

In the past, South Africa had a reasonably robust research programme in Forest Entomology. However, in recent years, forest entomology research and services in South Africa have become fragmented and substantially eroded. Capacity since 1990 has seriously dwindled, when approximately 10 people conducted research in this field.

A review of forestry research in South Africa in 1995 identified various threats to forestry research and development. Some of these factors have also contributed to the present lack of Forest Entomology research capacity. One such factor was scientist movement out of forestry research into research management, education, other fields or overseas. Another was the lack of planning for the succession of personnel and transfer of experience, partly because of the fragmented structure in most organisations. Uncertain research funding appears to have had a destabilizing effect on scientists and their associated research institutes (unpublished Bill Dyck report, 1995).

Key forest industry role players have recognized that an appropriate long-term strategy should include the view that forest entomology and forest pathology are closely disciplines. These fields require interchangeable skills that would best reside together in a combined research facility. Sustainable Forest Entomology and capacity building requires a "critical mass" of active participants. This is consistent with recommendations emerging from various reviews of forestry research in South Africa (unpublished Bill Dyck report, 1995). A further view was that it should be possible to establish a sound base of forest entomology, alongside pathology, and that significant synergy would emerge from having these disciplines combined.

FUTURE PROSPECTS

Survey of research needs

During 2000, the Forest Owners Association undertook to launch a survey of the Forest Entomology research needs of various industry participants. Participants identified all their entomological needs and listed the four most important needs in order of priority. These were further classified as a current or potential problem and the severity and financial loss associated therewith was estimated. The actions that participants currently use to address these problems were identified (diagnosis, monitoring, remedial). Participants also rated the importance of services (monitoring, diagnosis, extension, and research) required for each prioritised need. These responses were evaluated to develop a broad series of priority research areas.

Some trends emerged from the results of the survey (Table 2). Responses on specific insects were condensed into categories (damage, control measures, research action required) to accommodate the variable nature of the responses to questions posed.

Research focus areas

Pests that cause poor establishment of pine, wattle and eucalypt seedlings were identified as an important research focus area. Insects included members of the soil pest complex, for example, whitegrubs, cutworms, termites, *Hylastes angustatus* (bark beetles), millipedes, as well as above ground pests such as grasshoppers. Most respondents required research on impact assessment and alternative non-chemical methods to control these pests.

Insects that defoliate established pine, wattle and eucalypts constituted another key area of concern. This revolved around current and potential problems with wattle bagworm and wattle mirid, for example, determination of economic injury levels and impact assessment studies. The control of *Gonipterus* (Eucalypt snout beetle) attacking cold tolerant *Eucalyptus* species and to a lesser extent research on *Euproctis* (Pine brown tail moth) that defoliates pines, was also required.

Table 2. A breakdown of priority entomology research focal areas required by all South African commercial forestry industry participants.

COMPANY	**PRIORITY RESEARCH FOCAL AREAS**			
	1	**2**	**3**	**4**
A	Defoliating insects	Defoliating insects	Defoliating insects	-
B	Insects affecting seedling/sapling establishment	Insects affecting seedling/sapling establishment	Insects affecting seedling/sapling establishment	Insect/pathogen interactions
C	*Sirex* wood wasp	Biocontrol of all pests	Human resource development	Insects affecting seedling/sapling establishment
D	*Phoracantha*	New pests and incursions	Insects affecting seedling/sapling establishment	-
E	Insect/pathogen interactions	-	-	-
F	Monitoring + diagnosis	Monitoring + diagnosis	Research	Human resource development
G	Insects affecting seedling/sapling establishment	Insects affecting seedling/sapling establishment Defoliating insects	Defoliating insects Insects affecting seedling/sapling establishment	Defoliating insects
H	Insects affecting seedling/sapling establishment	*Sirex* wood wasp	Insect/pathogen interactions	Defoliating insects

* This information is a synthesis of responses to a questionnaire on Forest Entomology research needs conducted by the Forest Owners Association

Monitoring of the spread and augmentation of biocontrol of the *Sirex* wood wasp on pines in the Western Cape was considered important. However, the fact that the pest needs to be contained in the Cape and prevented from spreading northwards was not reflected in the results of the survey.

There were both general and specific requests for studies on insect-pathogen interactions. Research to determine the vectors of *Ceratocystis* wilt of wattle was considered a priority. Furthermore, the possible association of *Hylastes angustatus* with pathogens that infect pine seedlings was highlighted.

All respondents noted a significant need for extension, monitoring and diagnostic services. Failure to monitor the forest resource for new introductions of insects and diseases can have significant economic implications. Greater effort to reduce risks was required with surveillance (including quarantine) and strategies to minimise losses once introductions have occurred. Resistance breeding and the implementation of biological control were also identified as important. Human resource development, both of forestry personnel and postgraduate students was also highlighted amongst key requirements.

CONCLUSION

South Africa had an active Forest Entomology research programme in the past, which is renown for its many successful biological control initiatives. Existing insect pests, new incursions and quarantine failures, however, continue to threaten the health of plantation trees, and capacity to address these problems is lacking.

There is a need for long term (process) research to ensure that results can to be modelled and extrapolated beyond the immediate but necessary, short term applied (empirical) research. This type of strategic focus would also allow the use of molecular techniques to understand population genetic variability and to resolve taxonomic questions regarding important pests. Biological control programmes, for example, can then be designed to be more host-specific and matched to site and abiotic factors. There is also a need to determine the origin and history of spread of exotic pests to develop strategic control strategies.

The research directions to ensure that insect pests do not destroy South African forestry are clear. The forestry industry has identified pests of establishment and defoliators of wattle, pine and eucalypts; insect-pathogen interactions; new incursions; biological control and *Sirex* wood wasp as crucial research focus areas. Monitoring, extension and diagnostic services plus the creation of research capacity are also recognized as essential. A research programme in Forest Entomology needs to be revived, and it can draw synergy and derive impetus from a related programme in pathology (Tree Pathology Co-operative Programme), which is linked to student training, basic services and sustainable research.

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CHAPTER 3

Status of soil invertebrate pests of *Acacia mearnsii* regeneration in South Africa

ABSTRACT

Acacia mearnsii (wattle) plantations in South Africa comprises about 106 687 hectares. Wattle was previously grown mainly for the commercial potential of its bark (tannin extract) but it is now also managed on a short rotation for pulpwood. Clearfelled sites are continually being regenerated. Although, considerable research has been done on the post establishment insect pests of wattle, little is known about the incidence and status of soil invertebrate pests. Fourteen trials were planted, on previous wattle sites, over six growing seasons from 1990/91 to 1999/00. 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. Seedlings that failed to establish during wattle regeneration ranged from 8.95% to 50.84%, and the incidence of damage by soil invertebrate pests ranged from 2.15% to 30.21%. In sites where the plantation residue was windrowed and burnt, the average total incidence of soil invertebrate pests was 20.34%, and the average total failure of wattle seedlings to establish was 34.42%. Whitegrubs were the dominant and most economically important soil invertebrate pests (average incidence of 12.52%), followed by cutworms (average incidence of 3.97%) and grasshoppers (average incidence of 2.12%). Other soil invertebrate pests included termites, tipulid larvae, false wireworms, crickets, millipedes, ants and nematodes. Nematodes were sporadically important (11.58%) in old arable wattle sites. Although the prophylactic and corrective application of insecticides was widely used to control these pests at planting, their routine use in certified plantations contravenes the Forest Stewardship Council guidelines.

Keywords: seedling mortality, soil invertebrate pests, wattle, establishment

INTRODUCTION

Acacia mearnsii De Wild. was first introduced into South Africa from Australia in approximately 1864 (Hepburn 1973). It was primarily imported as a shade tree for livestock, for windbreaks and as a source of fuel wood on farms. It was only in 1884 that the commercial potential of wattle bark (tannin extract) was exploited (Hepburn 1973). Commercial wattle plantations have since expanded to their current holdings of 106 687 hectares despite a gradual decrease in the area under wattle of 1.3% per year during the last 20 years (Department of Water Affairs and Forestry 1980 - 2001). Wattle plantations are now grown and managed for pulpwood, mining timber, poles, bark extracts, charcoal, firewood and to a lesser extent for sawlogs.

A total of 329 species of invertebrates, especially insects, spiders and mites, have been recorded as being associated with wattle trees in South Africa (Hepburn 1966). Swain and Prinsloo (1986) listed 221 species of these invertebrates as being phytophagous on wattle. These phytophagous invertebrates represent various feeding guilds (leaf eaters, leaf miners, gallers, sap suckers, flower and bud feeders, seed insects, wood borers, shoot borers, bark feeders and root feeders) and belong to the orders Coleoptera (46.1%), Lepidoptera (35.7%), Hemiptera (11.8%), Isoptera (3.6%), Psocoptera (1.4%), Orthoptera (0.9%) and Thysanoptera (0.5%). All the insect pests that damage wattle in South Africa are indigenous. Most of them had low pest status prior to them colonising and exploiting the resource rich, exotic commercial wattle plantations. Besides a few attempts to control the wattle bagworm with natural biological agents (Hepburn & Borthwick 1968; Hepburn 1969a; Ossowski 1960), there has been a reluctance to use biological control as a tactic to manage wattle pests in the past because of the view (Atkinson 1997) that these indigenous pests already have their complement of natural enemies and are therefore best controlled with the preventative or corrective use of insecticides.

There is a limited availability of land and water to agriculture in South Africa (Vlok & Van der Merwe 1999) and commercial forestry is often in intense competition with other agricultural crops for these valuable resources. To maximize yields in a limited area, there has been a corresponding shift from extensive to intensive silviculture of wattle (Schönau 1990), hence a renewed interest in the management of wattle pests, especially soil invertebrate pests that affect the establishment of new transplants. Although a failure of wattle seedlings to establish (variable value from 16.6% to 31.0%) has been recorded (Rusk *et al.* 1992, 1993, 1994), the causes of this mortality were vaguely known. Annotated checklists of wattle pests have been compiled (Hepburn 1966; Ossowski & Wortmann 1960; Sherry 1971; Swain & Prinsloo 1986), which reported the general incidence of damage and associated pest species. However, the pest status and impact of most soil invertebrate pests are poorly understood and in many cases unknown. High risk areas and the reasons for soil invertebrate pest outbreaks have only recently been identified (Chapter 4) which precluded any strategic planning in planting programmes and silvicultural budgeting in the past. Foresters often replant dead seedlings when a mortality threshold of greater than 10% is observed, with no corrective or preventative action because of a lack of understanding of the causes of mortality. Alternatively, a general recommendation of the preventative use of a pesticide at planting is financially wasteful, short sighted in terms of strategic planning, and environmentally hazardous. This practice is also prohibited by the Forest Stewardship Council (FSC) certification guidelines (Chapter 7) (Qualifor 2002).

MATERIALS AND METHODS

Fourteen trials were planted on previous wattle sites, over six growing seasons (1990/91 to 1999/00) to determine the mortality factors affecting the regeneration of wattle. Sites were selected in representative regions of the wattle production area where the plantation residue management varied according to the practice of the region. Trial 1 (Seven Oaks: 29° 12′ S, 30° 38′ E), trial 2 (Umvoti: 29° 11′ S, 30° 27′ E), and trial 3 (Melmoth: 28° 31′ S, 31° 17′ E) were a randomised complete block design with 12 plots/replicate (20 trees/plot), and replicated six times. Trial 4 (Pietermaritzburg: 29° 32′ S, 30° 27′ E), trial 5 (Richmond: 29° 49′ S, 30° 17′ E) and trial 6 (Hilton: 29° 34′ S, 30° 16′ E) were a randomised complete block design with eight plots/replicate (20 trees/plot), and replicated six times. Trial 7 (Seven Oaks: 29° 11′ S, 30° 40′ E) was a randomised complete block design with five plots/replicate (20 trees/plot), and replicated 10 times. Trial 8 (Pietermaritzburg: 29° 33′ S, 30° 27′ E), trial 9 (Pietermaritzburg: 29° 33′ S, 30° 27′ E) and trial 10 (Seven Oaks: 29° 10′ S, 30° 39′ E) were two adjacent 5 plot x 5 plot latin square designs (20 trees/plot), and replicated 10 times. Trial 11 (Pietermaritzburg: 29° 32′ S, 30° 28′ E), trial 12 (Iswepe: 26° 48′ S, 30° 37′ E) and trial 13 (Iswepe: 26° 48′ S, 30° 37′ E) were a randomised complete block design of five tree species per replicate (total four) with 100 trees/plot. Only one of the five tree species in each trial was wattle (Chapter 1). Trial 14 (Wakkerstroom: 27° 21′ S, 30° 38′ E) was a 5 plot x 5 plot latin square design of five 5 tree species (plot) per replicate with 120 trees/plot, and only one of the five tree species was wattle (Chapter 1). Large trials with many trees per plot were planted because of the aggregate nature of soil invertebrate distributions (Allsopp & Bull 1989: Edwards 1991).

Sites where the plantation residue was windrowed and burnt and weeded (manual or post emergent herbicide spray) was the most common practice for wattle regeneration, and therefore mainly used to evaluate the status of soil invertebrate pests. Although the effect of the different plantation residue management practices [windrowed-burnt-weeded, windrowed-burnt-ripped, fallow (mowed, manual weed), windrowed-burnt-closer spacing, windrowed-'broadcast'-herbicide] on the incidence of soil invertebrate pests was evaluated in Chapter 4, the change in status of soil invertebrate pests during these differing plantation residue management practices was also evaluated.

All seedlings and subsequent surviving seedlings were evaluated monthly for a period of six months after planting. During each survey all stressed, damaged and dead seedlings were systematically dug together with approximately 0.012 m^3 of the surrounding soil to determine the cause of death. With practice it became easier to recognise the damage caused by the various soil invertebrate pests and these mortality factors were confirmed in most instances by the presence of the pest. Mortality was expressed as a percentage loss of establishment (number of stressed, damaged and dead seedlings per mortality category versus the total number of seedlings planted), where damage by soil invertebrate pests is equivalent to percentage infestation. Although all mortality factors were determined, including an unknown category, only soil invertebrate pest infestations were evaluated in this paper because most other mortality factors can be overcome with a more careful application of existing silvicultural and nursery practices. It was not possible to determine the incidence of pathogens because most seedlings dried out during the monthly survey interval and the isolation for pathogens only showed saprophytes.

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 include a discussion on pests that were not observed in the trial series.

Table 1: Percent incidence of soil invertebrate pests during the regeneration of wattle seedlings in South Africa. (Clustered according to the similarity of the plantation residue management regime). (WBW: windrowed-burnt-weeded, WBH: windrowed-broadcast-herbicide, WBR: windrowed-burnt-ripped, FMO: fallow-mowed, FMW: fallow-manual weed, WBS: windrowed-burnt-closer spacing, WBA: windrowed-burnt-old arable land). (T 1 to T 14: trials 1 to 14).

Soil invertebrate pest	**Clustered plantation residue management regimes**																
	windrowed-burnt-weeded; broadcast									**fallow; ripped**				**espacement**			**arable**
	WBW	WBW	WBW	WBW	WBW	WBH	WBW	WBW	**avg**	WBR	FMO	FMW	**avg**	WBS	WBS	**avg**	WBA
	T 1	T 4	T 8	T 9	T 11	T 12	T 13	T 14		T 2	T 5	T 6		T 3	T 7		T 10
whitegrubs	10.70	18.85	10.62	12.89	13.67	9.17	9.17	15.07	**12.52**	0.94	0.88	0.28	**0.70**	4.73	5.39	**5.06**	**2.37**
cutworms	0.53	0.75	2.97	1.77	11.08	7.00	6.29	1.39	**3.97**	1.96	0.57	1.79	**1.44**	2.52	1.33	**1.93**	**1.76**
termites	0.00	0.14	0.00	0.08	0.25	0.00	0.00	0.00	**0.06**	0.04	0.00	0.00	**0.01**	0.00	0.17	**0.09**	**0.00**
tipulid larvae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.28	**0.04**	0.00	0.00	0.00	**0.00**	0.00	0.00	**0.00**	**0.00**
millipedes	0.59	3.32	1.78	0.55	0.00	3.75	1.54	0.00	**1.44**	0.11	0.17	0.00	**0.09**	0.88	0.00	**0.44**	**0.33**
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**	0.38	0.00	**0.19**	**11.58**
wireworms	0.00	0.21	0.00	0.29	0.00	0.00	0.13	0.00	**0.08**	0.00	0.00	0.00	**0.00**	0.00	0.00	**0.00**	**0.66**
crickets	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.76	**0.12**	0.00	0.00	0.00	**0.00**	0.00	0.00	**0.00**	**0.00**
grasshoppers	0.00	0.00	0.00	0.67	2.63	10.29	2.00	1.39	**2.12**	0.00	0.14	0.08	**0.07**	0.00	0.17	**0.09**	**0.74**
ants	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.11	0.00	0.00	**0.04**	0.00	0.00	**0.00**	**0.00**
Total soil invertebrate pest incidence	11.82	23.27	15.37	16.41	27.63	30.21	19.13	18.89	**20.34**	3.16	1.76	2.15	**2.36**	8.51	7.06	**7.79**	**17.44**
Total loss of seedling establishment (all mortality factors)	33.94	33.86	23.15	27.31	40.75	36.50	29.00	50.84	**34.42**	8.95	12.65	41.03	**20.88**	30.03	11.83	**20.93**	**23.00**

RESULTS AND DISCUSSION

The incidence of soil invertebrate pest damage during the regeneration of wattle seedlings in South Africa was clustered according to the similarity of the plantation residue management regime (Chapter 4), and was presented in Table 1. This data was used to evaluate the status of these soil invertebrate pests and to describe their damage. The biology and control of these pests was overviewed in the light of knowledge gained while conducting this study and to collate information from numerous unpublished reports.

WHITEGRUBS

Status

Whitegrubs were the dominant and most important pests that affected the regeneration of wattle seedlings. An average of 12.52% of wattle seedlings failed to establish because of whitegrub damage in sites where the plantation residue was windrowed and burnt, and this mortality ranged from 9.17% to 18.85%. The incidence of whitegrub damage was significantly reduced when the plantation residue was windrowed, burnt and ripped or the site left fallow (average 0.70%) or when the seedlings were planted closer together (average 5.06%) (Table 1) (Chapter 4).

Biology

Whitegrub is the common name of the larvae of several species of leaf chafer beetles (Coleoptera: Scarabaeidae: Rutelinae, Melolonthinae) (Scholtz & Holm 1985). The adults of some species often defoliate pine and wattle trees. Whitegrubs are C-shaped, have three pairs of well-developed thoracic legs, a sclerotized head and are whitish with a blue tinge where the gut shows through the distended abdominal body wall. Size varies from 2.6 to 36.0 mm long, according to age and species of larva (Borthwick 1975). A particularly damaging species in the Natal Midlands is the large wattle chafer, *Hypopholis sommeri* Burm., where both the adult and larval lifestages are pests. Several species of whitegrubs have been recorded as either or both root feeders and defoliators of wattle while many species remain undescribed. Hepburn (1966) recorded about 26 species and Swain & Prinsloo (1986) recorded a further five species of scarabaeids that attack wattle. Some of the common genera are *Anomala*, *Adoretus*, *Hypopholis*, *Maladera*, *Schizonycha*, *Trochalus* and *Monochelus*.

Scarabaeid larvae are mostly found in soils with a high organic content because the early instars initially feed on organic matter in the soil and switch to root feeding during their second and third instars (Annecke & Moran 1982; Govender 1995). Whitegrubs are common during and after wattle rotations in the Natal Midlands (Carnegie 1974).

Eggs are laid in moist soil beneath the host plants, mainly during October to March. The eggs hatch after two to three weeks (Borthwick 1975). There are three larval stages before pupation in the soil. In some species, for example *Adoterus ictericus* Burm., there is one generation per year (Prins 1965) but in other species, for example *H. sommeri* and *Schizonycha affinis* Boheman, the life cycle may take up to two years (Annecke & Moran 1982). The consequent overlapping of generations results in waves of infestation (Sherry 1971), which further adds to the economic importance of whitegrubs in the regeneration of wattle.

Damage

Whitegrubs eat the roots and sometimes ringbark young seedlings up to the root collar region. This causes a reduction in growth and frequently the death of newly emerged or planted wattle seedlings when the root plug is devoured. Older saplings that develop sufficient lateral roots prior to whitegrub infestation are less affected and able to withstand subsequent whitegrub attack. Seedlings that are not killed by whitegrub attack often have stunted growth, which makes them more susceptible to frost damage during winter. Whitegrub damage of seedlings in the summer rainfall region begins soon after planting (October to April) and follows a bell shaped curve, peaking in February, and tails off towards winter. Transplants were most susceptible to whitegrub damage from December to April (Govender 1995). Although numerous whitegrub larvae were present during winter they were often deeper in the soil because of their vertical movement in response to soil moisture and temperature (Edwards 1991; Fleming 1972) and hence outside the root range of seedlings.

Control

Extensive trials have been conducted to evaluate the efficacy, formulations and method of application of various insecticides to control both whitegrubs and cutworms at planting (Govender 1993, 1995; Govender & Atkinson 1992, 1993). Three insecticidal treatments were subsequently registered for use against whitegrubs in forestry (Nel *et al.* 1999). These include deltamethrin 5% SC applied as a drench at a rate of 0.025 g active ingredient (a.i.)/seedling at planting in 1 to 2 litres of water), gamma BHC 0.6% DP applied around the root plug at a rate of 0.06 g a.i./seedling in the planting pit and carbosulfan 10% CRG applied around the root plug at a rate of 1.00 g a.i./seedling in the planting pit. Another insecticide that was also effective in these experiments was chlorpyrifos 10% CRG applied around the root plug at planting at a rate of 1.0 g a.i./seedling (Govender 1995). This treatment has not been registered for use against whitegrubs in forestry. In line-sown wattle, Borthwick (1975) proposed that gamma BHC 0.6% DP be sprinkled into the furrow at the rate of at least 11 kg per hectare and that nursery beds or sleeves be dusted at the rate of 30 g/m^2 to achieve whitegrub control. The use of gamma BHC, an organochlorine insecticide, is however, prohibited in terms of FSC regulations (Qualifor 2002, Chapter 7).

CUTWORMS

Status

Cutworms were the second most frequent and important soil pest (but with about a threefold lower status than whitegrubs) that affected the regeneration of wattle seedlings. Cutworm infestations in sites where the plantation residue was windrowed and burnt caused an average of 3.97% (range from 0.53% to 11.08%) damage to wattle seedlings. They assumed a twofold (1.44%) higher status than whitegrubs (0.70) in sites that were left fallow or ripped after being windrowed and burnt because of the greater presence of weeds that could support a larger population of cutworms. However, the average incidence of cutworm damage on the latter sites was still lower than on sites that were windrowed and burnt (Table 1).

Biology

Cutworms are the caterpillars of numerous species of *Agrotis* moths (Lepidoptera: Noctuidae). *Agrotis segetum* Schiff. and *A. longidentifera* Hmpsn. have been observed to damage wattle seedlings (Sherry 1971). The mature caterpillars are about 35 mm in length, dull-greyish or brown in colour, lack secondary setae (hairless, waxy appearance), and curl up into a tight ring when disturbed. The moths have nondescript greyish or brownish forewings and whitish hindwings, are strong nocturnal fliers, and attracted to light (Annecke & Moran 1982).

Eggs are laid singly or in clusters on the soil or host plants and hatch after 3 to 15 days. An adult female can lay between 1000 and 2000 eggs. There are six larval instars lasting from 20 to 128 days and the pupal stage takes 9 to 45 days, depending on the species and climatic conditions (Annecke & Moran 1982). They can have many generations during summer and seedlings are susceptible throughout the planting season. The insects tend to over-winter in the larval stage.

Damage

Soon after planting, cutworms sever the stems of seedlings at their bases at ground level, which are dragged underground before the leaves are eaten. They tend to move from one plant to another along the row. Seedlings either die, become vulnerable to frost damage during winter or growth is set back for some time while coppicing. Older seedlings, where the bark on the stem has hardened, may often be ringbarked at the root collar. Callous tissue develops around the wound in actively growing seedlings and forms strongly elbowed stems that later break; hence cutworm damage impacts beyond the establishment phase. Some damaged seedlings are out-competed by weeds and die or break off in the wind. Young cutworm larvae can climb the stems and sever the tender branches of older seedlings. Older larvae tend to feed nocturnally at the root collar, and during the day they seek refuge in the soil or beneath debris around the bases of seedlings.

Cutworm damage is very common in sites where the plantation residue has been windrowed and burnt prior to wattle regeneration. Fire breaks the dormancy of wattle seed and results in a flush of wattle seedlings, which is selected by adult moths for oviposition. Poor weed control also aggravates cutworm damage because weeds support a larger cutworm population, which feed aerially in the earlier instars before becoming subterranean (Annecke & Moran 1982). Cutworm damage occurs throughout summer into autumn. The younger the seedlings, the more prone they are to cutworm damage.

Control

The same trials that were conducted to evaluate the efficacy, formulations and method of application of various insecticides for the control of whitegrubs, were also tested for control against cutworms at planting (Govender 1993, 1995; Govender & Atkinson 1992, 1993). Deltamethrin 5% SC applied as a drench at a rate of 0.025 g a.i./seedling in 1 to 2 litres of water at planting was subsequently registered for use against both whitegrubs and cutworms in forestry. Several other insecticides are also registered for use against cutworms of other crops, for example, alpha-cypermethrin, beta-cyfluthrin, chlorpyrifos, cyfluthrin, cypermethrin, cypermethrin-high cis, deltamethrin, endosulfan, esfenvalerate, fenvalerate, lambda-cyhalothrin, permethrin, quinalphos, sodium fluosilicate, tau-fluvalinate, tralomethrin and trichlorfon (Nel *et al.* 1999). The different methods of applying these insecticides depend on their formulation and include pre and post-emergence spraying, row application, aerial application and pre-emergence bait application at specified dosages. Spray treatments should preferably be applied when the top three to five centimetres of soil is moist. The traditional practice of sprinkling gamma BHC dusting powder around the seedling (Sherry 1971) was ineffective against cutworms (Govender 1995).

TERMITES

Status

Very rarely does one encounter termite damage (average 0.06%) during the regeneration of wattle plantations (Table 1). Termites are infrequent pests of wattle. However, when present, especially during first conversion from grassland to forestry, can cause extensive damage to seedlings (Sherry 1971).

Biology

Termites (Isoptera: Hodotermitidae, Termitidae) are social insects with four different castes. Fungus-growing termites viz. *Macrotermes natalensis* Haviland, *Macrotermes falciger* Gerstäcker and *Macrotermes mossambicus* Hagen cause most damage. Termites appear to be associated with deep, well drained soils in warmer (north of 30^{0}S latitude, below about 1300 m altitude) and drier areas (less than about 900 mm mean annual rainfall) (Atkinson *et al.* 1991). *Macrotermes natalensis* is by far the most common species and their hard conical mounds are characteristic of the drier areas of KwaZulu-Natal and Mpumalanga. *Odontotermes* sp. was occasionally involved in damage along the south coast of KwaZulu-Natal, very rarely *Microtermes* (Sherry 1971). *Hodotermes mossambicus* Hagen was also reported to cause damage to wattle in the eastern Cape, KwaZulu-Natal and south-eastern Mpumalanga (Hepburn 1966; Ossowski & Wortmann 1960; Sherry 1971). Adult workers of the fungus grower termites gather plant fibre and this digested vegetable matter, which is produced as faecal pellets forms the basis of a fungus garden that is constructed within the nest and tended by workers.

Damage

Termites eat the roots, root collar and bark of living plantation trees. Trees are ring-barked and the wood is whittled away so that the damaged tap and lateral roots have a tapered and roughly sand papered appearance. Seedlings are killed and young trees are attacked throughout the year for up to two years in wattle. Trees consequently cannot be firmly anchored in the soil, which leads to windthrow and a resultant reduction in stocking (Sherry 1971). Damage usually ceases when the canopy closes (Atkinson 1991), and although nests may survive canopy formation damage to subsequent rotations is rare. Termite damage to wattle can be extensive when the trees are planted in ex-grassland sites (Sherry 1971). Termite activity can be detected before land preparation, not only by the presence of visible nests but also by the soil sheeting constructed over stumps, twigs, dry grass stems and dry cattle dung.

Control

Carbosulfan 10% CRG applied around the root plug in the planting pit at a rate of 1.00 g a.i./seedling is the only treatment registered for use against termites in forestry (Nel *et al.* 1999). The exorbitant cost of carbosulfan and its unavailability in South Africa are two important constraints to this recommendation. Chlordane 60% EC was previously registered for use in forestry, but has subsequently been withdrawn (Nel *et al.* 1999) and being a chlorinated hydrocarbon insecticide, is prohibited in terms of FSC regulations (Qualifor 2002). The traditional practice of nest fumigation during or before land preparation (Sherry 1971) is not recommended because not all nests are visible above ground as mounds and this practice also has a negative environmental impact in that termites also serve a useful function in nutrient recycling. The seedlings themselves should rather be protected with insecticide until canopy closure when the trees are no longer attacked.

GRASSHOPPERS

Status

Grasshoppers were regularly recorded as a low occurrence (2.12%) pest of wattle seedlings. Although a maximum of 10.29% incidence of grasshopper infestation was recorded in the site where the plantation residue was 'broadcast', this is an overestimation. The plantation residue was windrowed and only broadcast prior to planting, allowing grass and weeds to accumulate on the site. This allowed a build up of grasshoppers and also the migration of grasshoppers from an adjacent site that was windrowed and burnt (Table 1). Grasshoppers usually increase in numbers in fallow areas, and when these areas are treated with herbicide prior to planting the resident orthopteran population concentrates its feeding on the wattle seedlings. A more appropriate average incidence of grasshopper damage would be about 0.96%, when the result from the 'broadcast' site was excluded (Table 1).

Biology

Numerous species of phytophagous short-horned grasshoppers, for example *Duronia chloronota* Stål. (Orthoptera: Acrididae), attack wattle seedlings but a common pest is the elegant grasshopper, *Zonocerus elegans* Thunb. (Orthoptera: Pyrgomorphidae) (Hepburn 1966). *Zonocerus elegans* is very common in sparse vegetation and often occurs on bare soil. Most are aposematically coloured in red, yellow, green or blue and produce repugnatorial secretions. Young grasshopper nymphs generally feed on monocotyledons (grasses) whereas the later instars prefer dicotyledons (Scholtz & Holm 1985).

Each female (*Z. elegans*) can lay about three egg packets (between 30 and 100 eggs per packet) in loose soil during late summer (March to April). These eggs overwinter and hatch when the temperature increases and after the first spring rains (Annecke & Moran 1982). Nymphs and adults are present for about six months, which coincides with the planting season in the summer rainfall area. Therefore the blanket treatment of competing vegetation and weeds with herbicides prior to planting accentuates grasshopper damage of wattle seedlings.

Damage

Grasshoppers sever the young stems and branches of seedlings. In instances where the stem has been partly damaged, the stems often snap off at these weak spots. Late detection of this type of damage can be confused with cutworm or duiker browsing damage.

Control

Although no insecticides are registered for use against grasshoppers in forestry, several insecticides are registered for use against these pests affecting other crops (Nel *et al.* 1999). Various formulations of carbaryl, for example, carbaryl 85% WP (wettable powder) at a rate of 127.5 g a.i./100 *l* water, sprayed from a knapsack applicator, can be used against the elegant grasshopper. Deltamethrin 5% SC at a rate of 0.15 g a.i./100 *l* water is used to control short-horned grasshoppers. It has been reported that the tannins present in wattle leaves and stems have a toxic effect and exert control on *Schistocerca gregaria* Forsk. in Morocco (Sherry 1971).

MILLIPEDES

Status

Millipedes were a recurrent but low status pest of wattle seedlings. The average millipede damage was 1.44% in sites where the plantation residue was windrowed and burnt. The highest incidence of millipede damage was recorded in the site where the plantation residue was broadcast (3.75%) (Table 1). One can expect their status as pests to increase with the move towards the broadcasting of plantation residue because such practices favour the breeding of millipedes.

Biology

Millipedes (Diplopoda: Juliformia) are usually found in soil, debris, under stones or bark and often accumulate under brush piles in forestry. They are active after summer rains. Eggs are laid in small nests made of hard earth, over which the female keeps guard. Several species may be involved, but only the identity of *Orthoporoides pyrrocephalus* Krabb., which is widely distributed in localised areas of South Africa, has been recorded (Lawrence 1984). *Orthoporoides pyrrocephalus* is reported to show little discrimination in its choice of food. However, Lawrence (1984) states that millipedes should not be regarded as pests of primary importance and that in general they prefer already damaged (by other soil invertebrate pests) and decaying plant tissue (by soil pathogens) as food. Millipede attack should therefore be construed as a symptom rather than a cause of damage.

Damage

There is still some uncertainty about the exact nature of the damage that millipedes cause. The roots of seedlings may be damaged or destroyed, either mechanically by burrowing into the root plug or by feeding. Where damage has already begun by other soil invertebrate pests, millipedes may be present in sufficient numbers to aggravate the injury. There have been reports that millipedes emerge from brush piles in summer and move along the rows of seedlings, chewing the stems at or above soil level (Atkinson 1997). The stems may be severed, or broken at the calloused wound or the seedling may be ringbarked (similar to cutworm damage). In Western Nigeria, *Odontopyge* species has been reported as a pest in nursery beds of *Gmelina arborea* Roxburgh (yemane trees) and *Tectona grandis* Linnaeus (teak trees) in the high forest zone, where it destroys young seedlings by eating through the stems (Browne 1968).

Control

Although no insecticides are registered for use against millipedes in forestry, a bait is registered for use against this pest in other crops (Nel *et al.* 1999). Methiocarb 80% WP can be prepared as a soft porridge bait at a rate of 200.0 g a.i./bait mixture (with 10 kg bran and 15 litres of water). This bait is strategically distributed in the field during the late afternoon when the pests become active.

NEMATODES

Status

Nematodes were sporadic pests of wattle but when present in large numbers, especially on old arable land, caused extensive damage (11.58%) (Table 1). An accurate estimation of the status of nematodes was difficult because wattle seedlings were seldom killed but showed stunted growth with sparse and chlorotic foliage, which could also be attributed to other silvicultural causes.

Biology

The plant parasitic nematodes (Nematoda), commonly called eelworms, are microscopic, slender, transparent worms living in the soil. Most are free-living and feed on the roots of plants, while others are parasitic in the roots. *Meloidogyne javanica* Treub. (Heteroderidae), causes root knots in which the females are obligate parasites (Sherry 1971). *Paratrichodorus* (Trichodoridae) is another debilitating ectoparasitic nematode that accumulates at and feeds on the growing tips of roots, resulting in root necrosis and terminal thickening of the roots. Other genera found attacking wattle seedlings included *Pratylenchus*, *Helicotylenchus* and *Xiphinema* (Govender 1993).

Damage

Plant parasitic nematodes seldom kill the plant but debilitate it, and fungal pathogens may gain access through the lesions they cause. Nematodes damage the roots of seedlings, which interferes with the normal functioning of the root system and this causes stunted growth. Damage by *M. javanica* results in the formation of small nodules, galls or knots that are different to the nitrogen fixing rhizobium nodules, which have distinct stalks.

Control

Although no nematicides are registered for use in forestry, aldicarb 15% GR applied at the rate of 0,75 g a.i./m^2, is registered for use against this pest affecting other crops (Nel *et al.* 1999). Aldicarb, like most systemic nematicides is normally phytotoxic, so caution needs to be exercised in trying to adapt this recommendation for use in forestry. Carbosulfan 10% CRG at 1 g a.i./seedling, although not registered against nematodes in forestry, effectively controlled nematodes under experimental conditions (Govender 1993). Nematode damage is more prevalent in sandy soils with a low organic content but when the humic content of the soil has been built up by the broadcasting of plantation residue, wattle seedlings are seldom affected by nematodes (Sherry 1971). Decomposition of organic matter promotes the build up of nematophagous fungi and predatory nematodes that can suppress parasitic nematode populations (Kleynhans *et al.* 1996).

TIPULID LARVAE

Status

Tipulids are infrequent, low status pests of wattle seedlings. In only one trial was tipulid larval damage (actual infestation of 0.28%, average 0.04%) recorded during the regeneration of wattle plantations (Table 1).

Biology

Tipulid or cranefly larvae (Diptera: Tipulidae), commonly called 'leather jackets' are seldom encountered as pests. However, the larvae of some soil-inhabiting species can be destructive feeders on subterranean parts of plants (Scholtz & Holm 1985). *Nephrotoma* spp. has been recorded in association with wattle in South Africa (Hepburn 1966). *Nephrotoma sodalis* Loew strips the bark from the roots of *Pinus strobus* Linnaeus seedlings and is recorded as a pest in North America and Canada (Browne 1968). *Tipula paludosa* Meigen is an introduced pest that attacks white spruce seedlings in the coastal areas of British Columbia (Sutherland & Van Eerden 1980).

Damage

Tipulid larvae girdle the stem above and below the soil line, thereby affecting water transport to the shoots. They may also consume some of the upper roots.

Control

No control measures have been developed for tipulid larvae in South Africa. In British Columbia tipulid larvae have been observed to survive in fallow moist soil by feeding on decaying seedling roots and weed roots. Larvae are therefore susceptible to desiccation (Sutherland & Van Eerden 1980), and discing or shallow ripping of the soil and keeping a site weed free would reduce tipulid larvae infestations.

WIREWORMS

Status

Wireworms were low status, occasional pests of wattle seedlings, especially in sites where the plantation residue was windrowed and burnt. The average incidence of wireworm damage was 0.08% with a maximum of 0.66% in an old arable site (Table 1).

Biology

Four species of wireworms (Coleoptera: Elateridae) are listed as being associated with wattle, but only the larvae of *Agriotes* spp. is listed as a pest of wattle seedlings (Hepburn 1966). The larvae of some species of *Agriotes* are major agricultural pests in Europe and the United States of America but only occasionally attack the roots of wheat and tubers of potatoes in South Africa (Scholtz & Holm 1985). False wireworm larvae (Coleoptera: Tenebrionidae) are pests on the roots of various cultivated crops in South Africa (Scholtz & Holm 1985). The larvae of *Somaticus varicollis varicollis* Koch and adults and larvae of *Gonocephalum simplex* Fabricus are recorded as pests of maize in KwaZulu Natal (Drinkwater 1989). *Gonocephalum simplex* is also recorded on a wide spectrum of field crops in Zimbabwe (Mlambo 1983). Larvae of *Somaticus angulatus* Fahraeus are regarded as one of the most economically important pests of maize and groundnuts in South Africa (Drinkwater & Giliomee 1991; Van Eeden *et al.* 1994a, 1994b). Whilst the wireworm and false wireworm species attacking new afforestation in ex-arable lands are known, many of the species found in forestry soils require identification.

Damage

Adults tenebrionids chew the bark off stems and sometimes wattle seedlings are ringbarked at ground level. while the larvae damage the subterranean parts of seedlings. especially the roots.

Control

No insecticides are registered for use in forestry. However. gamma BHC 0.6% DP applied at a rate of 40 kg/ha for wireworm and false wireworm larvae and quinalphos 0.5% RB applied at a rate of 5-10 kg/ha for adult tenebrionids. is registered for use against these pests in other crops (Nel *et al*. 1999).

CRICKETS

Status

Crickets were occasional pests of wattle seedlings. The incidence of damage averaged about 0.12% with a maximum of 0.76% in sites that were windrowed and burnt (Table 1). Crickets usually became resident in areas that had been left to weeds and were problematic on wattle seedlings especially during dry conditions when these areas were treated with broad-spectrum herbicides prior to planting.

Biology

Crickets (Orthoptera: Gryllidae) are widespread. nocturnal insects which live in and on the ground. under stones or logs or amongst fallen leaves by day. emerging at night to feed on seedlings of cultivated crops (Scholtz & Holm 1985). The shiny black cricket. *Gryllus bimaculatus* Degeer is about 25 mm long and usually has a conspicuous yellowish mark on either side at the base of the forewing. *Brachytrypes membranaceus* Drury has also been identified as damaging to wattle plantations (Hepburn 1966).

Damage

Crickets strip the bark off the stems of seedlings at ground level and feed on the underlying tissue. Late detection diagnosis presents as a dried frayed and ringbarked stem.

Control

Although no insecticides are registered for use against crickets in forestry, mercaptothion 50% EC at a rate of 12.5 g a.i./10 *l* water, as a full cover spray, is registered for use in ornamental plants, flowers and lawns against crickets (Nel *et al*. 1999).

ANTS

Status

In only one trial have ants been implicated in the mortality of regenerated wattle seedlings, with an infestation of 0.11% (Table 1).

Biology

Although *Anoplolepis custodiens* Sm. is usually associated with honeydew secreting scale insects on wattle (Hepburn 1966), these ants were also observed to mine soil from the planting pits of wattle seedlings (Pest & Diseases Database).

Damage

Ants were observed to mine the soil from seedling planting pits, thereby creating air pockets around the rootplug.

Control

No control measures are warranted.

OTHER WATTLE 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 wattle seedlings, but were not encountered in this study. Adults of various leaf beetles (Coleoptera: Chrysomelidae), for example *Peploptera curvilinae* Jac., *Colasposoma semihursutum* Jac., and several closely related species defoliate wattle seedlings, whilst their larvae feed on the roots. Curculionid adults of *Ellimenistes laesicollis* Fhs., *Catamonus melancholicus* Boh. and *Protostrophus lugubris* Mshl. defoliate and chew the bark of wattle seedlings causing the stems to break. The brown wattle mirid, *Lygidolon laevigatum* Reut. (Hemiptera: Miridae) causes serious defoliation of wattle seedlings.

Damage by soil invertebrate pests creates wounds, which permit the entry of fungal pathogens, for example, *Fusarium* spp., *Phytophthora* spp. and *Cylindrocladium* spp. (Pest & Diseases DataBase) or seedlings become stressed and secondary pathogen invasion cause their death. 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). The current insecticide recommendations for soil invertebrate pests of wattle seedlings are, however, in contravention of the Forest Stewardship Council guidelines, and are evaluated in Chapter 7.

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CHAPTER 4

Effects of plantation residue management on wattle regeneration pests in South Africa

ABSTRACT

The limited availability of land for the expansion of wattle plantations in South Africa has resulted in a shift from extensive to intensive silviculture. One way to increase productivity in a given area is to ensure the survival of seedlings during regeneration, thereby increasing the stocking of compartments. Soil invertebrate pests constitute one of the important causes of seedling mortality. The effect of different plantation residue management practices on the incidence of these pests is unknown. Fourteen trials were planted on previous wattle sites, over six growing seasons. Six different plantation residue management regimes [windrowed-burnt-weeded, windrowed-burnt-ripped, fallow (mowed, manual weed), windrowed-burnt-closer spacing, windrowed-'broadcast'-herbicide] 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. Members of the soil invertebrate pest complex included whitegrubs and cutworms that generally had a higher pest status than the millipedes, nematodes, grasshoppers, ants, false wireworms, termites and crickets. A higher incidence of cutworm damage was observed in the windrowed-burnt-ripped and fallow sites. There was a greater infestation of soil invertebrate pests on sites where the plantation residue was windrowed-burnt-weeded or 'broadcast' (20.34%) than in the other treatments [windrowed-burnt-ripped or fallow (mowed, manually weeded) 2.36%]. The addition of a rip treatment to a depth of above 50 cm in the windrow and burn regime significantly reduced the infestation of soil invertebrate pests, especially whitegrubs. Seedlings that were planted at a closer spacing in windrowed and burnt sites also had a lower incidence of soil invertebrate pest damage (7.79%). Regeneration of an old arable site had a sporadically high incidence of nematodes (11.58%) in the total 17.44% incidence of damage by soil invertebrate pests. This has important management implications because windrow and burn are standard plantation residue management practices in wattle silviculture. Pursuit of the sustainable silviculture of wattle warrants a move away from the burning of windrows (hot burns) to cool burns or the broadcasting of plantation residue. Planting is facilitated by the use of a tractor operated 'coulter ripper', which consists of a hydraulic cutting wheel and ripping tine on terrain with slopes of up to 40%. Insecticide application is the alternative option although its use is restricted by Forest Stewardship Council guidelines.

Keywords: slash management, seedling mortality, soil invertebrate pests, *Acacia mearnsii*

INTRODUCTION

The regeneration of wattle (*Acacia mearnsii* Wild.) plantations in South Africa has shifted over the years from extensive to intensive silvicultural management (Schönau 1990). The limited availability of arable land (Vlok and Van Der Merwe 1999) and the need for planting permits to expand these plantations (Department of Water Affairs and Forestry 1998) have largely necessitated this. Over the past 20 years, the area planted to wattle plantations in South Africa has decreased by 1.3% per year from 139 381 ha in the 1979/80 growing season to 106 687 ha in 1999/00 (Department of Water Affairs and Forestry 1981-2001).

One way to increase plantation productivity in a limited area is to ensure the survival of seedlings during regeneration, thereby increasing the stocking of trees within compartments. Numerous silvicultural parameters, for example, genetic improvement (Dunlop & Hagedorn 1998; Nixon 1977; Sherry 1971), site preparation (Boden 1984; Norris 1993, 1995; Sherry 1971), planting practices (Roberts & Kunz 1995; Sherry 1971; Sherry & Schönau 1966), fertilization (Beard 1952; Du Toit 1995; Herbert 1984; Schönau 1971), vegetation management (Little 2000; Sherry 1971), espacement and mensuration (Schönau 1982; Sherry 1971), soil type (Osborn 1931) and site-species matching (Donkin 1994; Herbert 1993; Schönau 1975) have been addressed to increase wattle productivity in South Africa. Another important aspect in the regeneration of wattle plantations is the management of harvesting residue from the previous rotation. Previous research has focussed on the effect of plantation residue management on the survival and growth of various species of seedlings from a weed management (Schumann *et al.* 1995; Little *et al.* 1996, 2000a, 2000b), fertilisation (Davis *et al.* 1996), harvesting impact (Smith 1998; Smith 2000), and site preparation (Allan 1998; Allan & Higgs 2000; Allan *et al.* 2000; Norris 1993, 1995; Lockett 1998; Schumann *et al.* 1994; Smith *et al.* 2000a, 2000b) perspective.

Soil invertebrate pests are some of the important factors that were often overlooked as a cause of seedling mortality in plantation residue management studies. Indigenous cultivators of slash-and-burn agriculture in the tropics practice burning to also control pests and diseases (Bandy *et al.* 1993). Some traditional plantation growers believe that the burning of plantation residue clears an area of pests prior to regeneration. Recently a view has been expressed that prescribed fire decreases the incidence of pests and diseases in established stands (Brennan & Hermann 1994). This dogma, which is cheap and easy to implement, together with the need to reduce fire hazard because of harvest residue fuel buildup and for ease of silvicultural operations during regeneration of wattle plantations, has resulted in the standard practice of windrowing and burning of plantation residue. The windrow and burn management of plantation residue has been recommended when wattle brush piles become large and unmanageable or there is a danger of frost damage to seedlings (MacLennan & Jarmain 1990). However, the promotion of sustainable management of wattle plantations (Norris 1993; Norris 1995; Sherry 1952) and adherence to Forest Stewardship Council guidelines (Qualifor 2002) prescribes a policy of not burning the plantation residue. The incidence of soil invertebrate pests and their status during the regeneration of wattle as a result of these different plantation residue management practices are unknown.

MATERIALS AND METHODS

Fourteen trials were planted on previous wattle sites, over six growing seasons (1990/91 to 1999/00). Sites were selected in representative regions of the wattle production area according to the plantation residue management practices and their frequency of application. Different plantation residue management practices [windrowed-burnt-weeded, windrowed-burnt-ripped, fallow (mowed, manual weed), windrowed-burnt-closer spacing, windrowed-'broadcast'-herbicide] were tested. Seedlings were evaluated monthly for a period of six months after planting. Stressed, damaged and dead seedlings were dug to determine the cause of death, which was expressed as a percentage loss of establishment. Only the mortality that was caused by soil invertebrate pests was evaluated in this paper.

Multivariate analyses of the soil invertebrate pest component of the mortality factors were performed using PRIMER 5 for Windows v5.1.2 2000 (Plymouth Routines in Multivariate Ecological Research), developed by the Plymouth Marine Laboratory, United Kingdom. Similarity matrices were calculated using Bray-Curtis coefficients for the percentage loss of establishment of seedlings by soil invertebrate pest species between localities. This similarity coefficient is considered to be one of the most robust coefficients because it is insensitive to joint species absences and is widely used in ecology (Clarke and Warwick 1994). From this similarity matrix a cluster analysis, using hierarchical agglomerative clustering and group-average linking, was performed and a dendrogram produced. Non-metric multidimensional scaling (MDS) was used to map the sample inter-relationships in an ordination of a specified number of dimensions. The dimensionality of the MDS ordinations plotted was chosen according to the acceptability of their associated stress values.

The differences in pest species structure were tested using ANOSIM (analysis of similarity) on the similarity matrix of each trial. This is a non-parametric permutation procedure applied to the rank similarity matrix underlying the ordination of samples. The Global R in ANOSIM is a test statistic indicating the degree of discrimination between groups or clusters and falls between 0 and 1. R equals 1 if all samples within a cluster are more similar to each other than any samples between clusters, and R approximates 0 when similarities between and within samples are similar on average.

RESULTS

The analysis of the similarity test produced a Global R sample statistic of 0.918, which showed that there are highly significant differences ($p = 0.001$) between clusters within the similarity matrix (Figure 1). These hierarchical clusters were arbitrarily named A, B, C and D according to the collective plantation residue management practice within each cluster. Cluster A had eight trials where the plantation residue was windrowed, burnt and weeded (7 trials) or broadcast (after initially being windrowed) with a herbicide application (1 trial). Cluster B had three trials where the plantation residue was windrowed, burnt and ripped (1 trial) or the site was left fallow for several seasons after harvesting and the weeds mowed prior to planting (1 trial) or the site was left fallow for a season and manually weeded prior to planting (1 trial). The plantation residue in the two trials within cluster C was windrowed and burnt but the seedlings were planted closer within the rows (either at 3m x 1.5m or 2m x 2m) rather than the standard spacing of 3m x 2m. The plantation residue in the single trial in cluster D was also windrowed and burnt but this was an old arable site adjacent to a sugarcane plantation.

In pairwise test comparisons of the clusters produced by ANOSIM, A and B ($R = 1$, $p = 0.006$) were significantly well separated and clusters A and C ($R = 0.728$, $p = 0.022$) overlapped slightly although they were significantly different. Clusters A and D ($R = 1$, $p = 0.111$), B and C ($R = 0.917$, $p = 0.100$), B and D ($R = 1$, $p = 0.250$) and C and D ($R = 1$, $p = 0.333$) were well separated despite their significance levels, which were low because of the few replicates in each cluster. In guidelines given by Clarke and Gorley (2000) these clusters are still considered different because the pairwise R values give an absolute measure of the separation of the clusters on a scale of zero (indistinguishable) to one.

The consistency of the results was checked with a non-metric multi-dimensional scaling (MDS) ordination (Figure 2). Clarke and Warwick (1994) recommended that even for strongly grouped samples, cluster analysis should be used in conjunction with ordination. The dimensionality (3-d and 2-d) of the MDS ordinations produced associated stress values of 0.03 and 0.06 respectively, giving confidence that the plot is an accurate representation of the sample relationships. A stress value of less than 0.1 gives a good ordination with little risk of misinterpretation (Clarke and Warwick 1994).

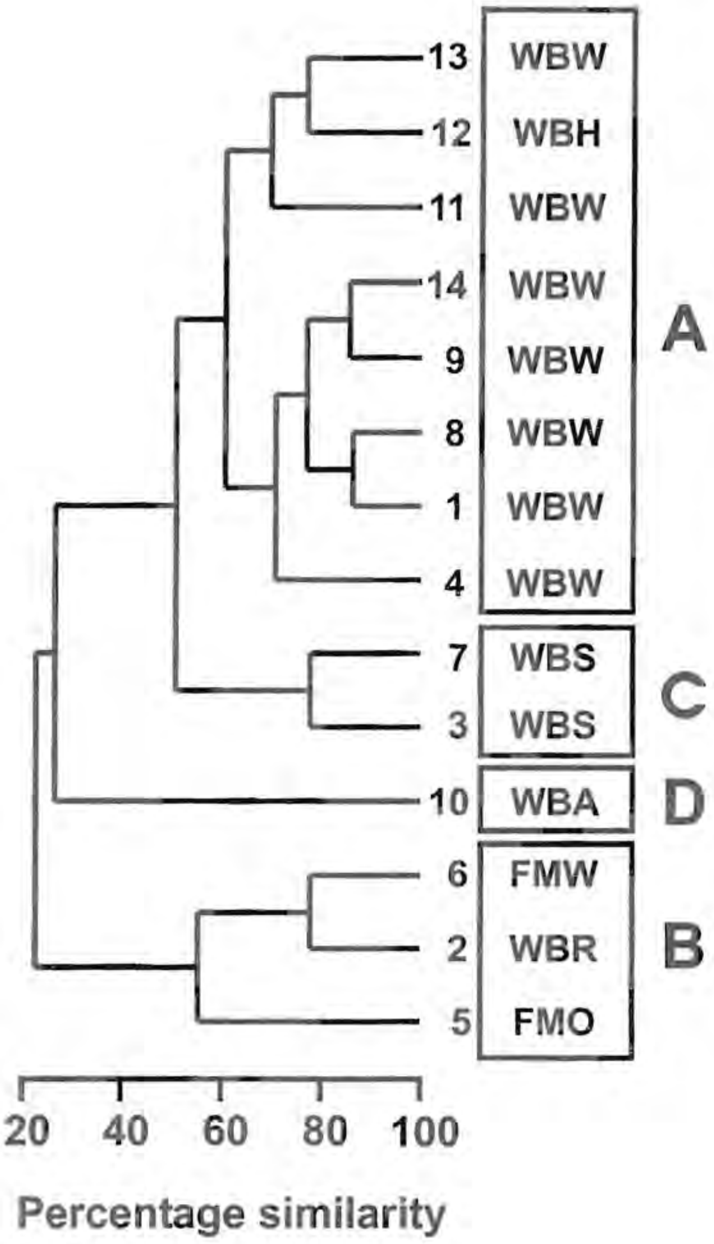

Figure 1. Dendrogram of Bray-Curtis percentage similariti es between fourteen wattle regeneration trials with varying plantation residue management regimes. (WBH, windrow-broadcast herbicide; WBW, windrow-burn-weeded; WBS, windrow-burn-closer spacing; WBA, windrow-burn-old arable; FMW, fallow-manual weed; WBR, windrow-burn-rip, FMO, fallow-mow).

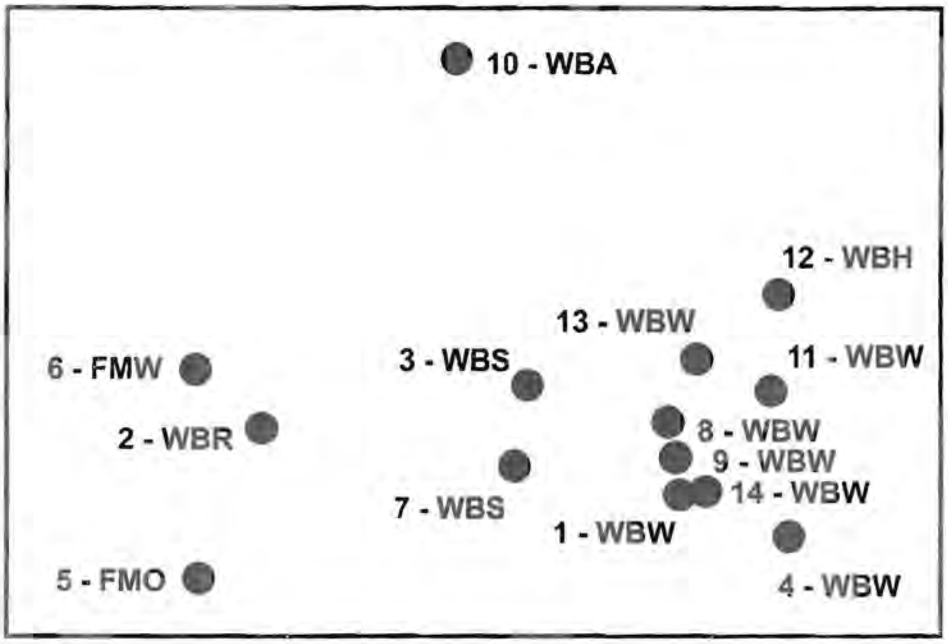

Figure 2. Ordination of fourteen wattle regeneration trials based on non-metric Multi-Dimensional Scaling of the soil invertebrate pest community structure (stress = 0.06) (scaled axes of these plots are unnecessary as the absolute distance between every pair of points on the ordination is a relative measure of their similarity).

Table 1. Incidence of soil invertebrate pests during the regeneration of wattle in different plantation residue management regimes (clustered according to analyses of similarity).

PEST MORTALITY FACTOR	PEST INCIDENCE (%) ACCORDING TO PLANTATION RESIDUE MANAGEMENT REGIME			
	Windrow - burn, Broadcast	**Windrow - burn - rip, Fallow**	**Windrow - burn, Espacement**	**Windrow - burn, 'Old arable land'**
	Cluster A (average)	Cluster B (average)	Cluster C (average)	Cluster D (average)
Whitegrubs	12.52	0.70	5.06	2.37
Cutworms	3.97	1.44	1.93	1.76
Termites	0.06	0.01	0.09	0.00
Tipulids	0.04	0.00	0.00	0.00
Millipedes	1.44	0.09	0.44	0.33
Nematodes	0.00	0.00	0.19	11.58
Wireworms	0.08	0.00	0.00	0.66
Crickets	0.12	0.00	0.00	0.00
Grasshoppers	2.12	0.07	0.09	0.74
Ants	0.00	0.04	0.00	0.00
% soil pest infestation	**20.34**	**2.36**	**7.79**	**17.44**
% total loss of establishment	34.42	20.88	20.93	23.00

The incidence of soil invertebrate pests from the various trials was averaged according to their cluster groupings in Figures 1 and 2 and presented in Table 1. The highest infestation (20.34%) by soil invertebrate pests was in trials where the plantation residue was windrowed and burnt or 'broadcast' (cluster A). Soil invertebrate pest infestations were progressively lower in the old arable site trial where the plantation residue was also windrowed and burnt (17.44%) (cluster D), followed by the trials where the plantation residue was windrowed and burnt and the seedlings planted at a closer spacing (7.79%) (cluster C) and by the trials where the plantation residue was either windrowed and burnt with the addition of a rip treatment or left fallow (2.36%) (cluster B). Soil invertebrate pests were responsible for 59.09%, 11.30%, 37.22% and 75.83% of the total trial mortality observed in clusters A, B, C and D respectively. These clusters usually had high pest species richness with low evenness but high dominance of a few pest species.

Indigenous soil invertebrate pests that caused the mortality of wattle seedlings included numerous species of whitegrubs (Coleoptera: Scarabaeidae), cutworms (Lepidoptera: Noctuidae), termites (Isoptera: Termitidae), tipulid larvae (Diptera: Tipulidae), millipedes (Diplopoda: Juliformia), various species of nematodes (Nematoda: Heteroderidae), false wireworms (Coleoptera: Tenebrionidae), grasshoppers (Orthoptera: Pyrgomorphidae, Acrididae), crickets (Orthoptera: Gryllidae) and ants (Hymenoptera: Formicidae) (Table 1). Whitegrubs and cutworms generally had higher pest status than the termites, tipulid larvae, millipedes, wireworms, grasshoppers and crickets. Although nematode damage was recorded, it was sporadic, but high (11.58%), in the trial that occurred in the old arable site. An unusually greater incidence of cutworm than whitegrub damage was observed in cluster B. In many of the trials though, whitegrubs were the most important and frequent soil invertebrate pest, followed by cutworms. The high incidence of soil invertebrate pest damage in the windrow and burn plantation residue management regime has important management implications because this is standard practice in commercial wattle silviculture in South Africa. However, leaving the site fallow or planting at a closer spacing, and especially the addition of a soil rip treatment with a single tine to a depth above 50 cm in the windrow and burn option, significantly reduced the infestation of soil invertebrate pests, especially whitegrubs.

DISCUSSION

The harvest residue of clear-felled wattle plantations is commonly piled along the rows of stumps (windrowed) and burnt prior to the regeneration of stands in most wattle growing regions of South Africa (Norris 1993; Norris 1995). This is a modification of the previous practice of burning the broadcast harvest residue to break the dormancy of wattle seeds, achieve even germination, destroy grass tufts and hence reduce weed control costs (O'Connor & Craib 1929). These advantages of burning in the previous era of extensive regeneration of wattle plantations are outweighed by numerous disadvantages. Burning of the plantation residue results in additional weeding costs during the control of natural wattle regeneration and delays in planting operations because of the need to burn under suitable weather conditions (MacLennan & Jarmain 1990). Cool burns, which are equivalent to prescribed fires (McRae 1994), are preferred if burning is necessary (Norris, 1995). During hot burns, carbon (Robertson 1998), nitrogen and sulphur may volatilise as gases. Increased rainfall reaching the soil may result in further loss of nutrients through leaching and surface movement. Furthermore, the exposed soil surface is exposed to wind and water erosion, and a breakdown of soil structure occurs because of the destruction of soil organic matter. Lastly, fire induces additional water repellency of the topsoil (Norris 1995). Although several insecticides have been successfully tested for their efficacy against whitegrubs (Govender 1995; Nel *et al.* 2002), burning of the plantation residue causes a buildup of carbon residue that becomes incorporated into the topsoil, which can absorb insecticides, thereby reducing their activity (Kamm & Montgomery 1990). This is further exacerbated by an increased incidence of soil invertebrate pests, especially whitegrubs, in sites where the plantation residue was windrowed and burnt.

The inclusion of a rip treatment to this plantation residue management regime and leaving the site fallow resulted in a significant fivefold reduction in the incidence of soil invertebrate pests. The effectiveness of the rip treatment is commensurate with about an eighteen-fold decrease in the incidence of the dominant whitegrub pests. Ripping the topsoil has the same effect as the cultural practice of ploughing and discing, which was traditionally used in agriculture to control whitegrub pests and prevent oviposition in the soil by adults (Veeresh 1977). Ripping also exposes the various lifestages of soil invertebrate pests to desiccation and further enhances predation by their natural enemies (Prins 1965).

Sites often remain fallow for several months before the next planting season. Some sites remain unplanted and unproductive for a few years, although it is uncommon in commercial operations. The grass and weed cover that develops is manually weeded, mowed if it is not too dense or a blanket herbicide treatment is applied prior to planting. During mechanical mowing or manual line cleaning there is still an abundance of grass and weed roots for the polyphagous whitegrubs to feed. The presence of vegetation in the interrow averts the migration of many native soil invertebrate pests (termites, tipulid larvae, millipedes, wireworms, crickets, and grasshoppers) onto newly transplanted wattle seedlings. Mowing and weeding operations results in mulch cover which conserves water and provides refuges for soil invertebrate pests that would otherwise be attracted to the moist planting pits of seedlings. An exception to this trend in windrow-burn-rip or fallow sites is the higher pest status of cutworm rather than whitegrub, unlike the case in all other plantation residue management regimes. It has been observed that the longer a site remains fallow, the lower the incidence of whitegrub damage because emerging beetles leave the site in search of their wattle hosts. A high density of weeds can support a larger population of early instar cutworm larvae, which feed above ground before switching to a subterranean feeding habit in their later instars (Annecke & Moran 1982). They actively search for tender stems, like those of young transplants, which are severed at ground level and dragged underground before the leaves are eaten.

Broad spectrum, systemic herbicides, for example glyphosate, are generally applied as a post-emergent spray (Grober *et al.* 2000) prior to the planting of wattle in most windrow and burn or late broadcast plantation residue management regimes. These herbicides kill both the aerial portions and roots of all potentially competing vegetation. Resident soil invertebrate pests divert their feeding onto the only remaining vegetation (young transplants), hence the higher incidence of soil invertebrate pest damage in these management regimes.

In the trial where the plantation residue was broadcast, the residue was first windrowed after harvesting and only broadcast a few weeks prior to planting. Effective broadcasting of the plantation residue is supposed to suppress the growth of weeds, and one can therefore expect a decreased incidence of damage by cutworms, grasshoppers, crickets, tipulid larvae and wireworms. Whitegrub distribution, however, is dependent on the feeding habit of adult beetles that oviposit in close proximity to these feeding sites (Fleming 1972). Hence one can still expect a high incidence of whitegrub damage in ex-wattle sites where the plantation residue is broadcast because some species of adult scarabaeids also defoliate wattle trees. Millipedes breed and seek harborage under decomposing brush piles and an increased incidence of damage can also be expected in sites where the plantation residue is broadcast.

Wattle seedlings are normally planted 1.5 m apart in rows, which are 3 m apart with an initial stocking of 2 222 trees per hectare. This is thinned to 2 000 trees per hectare after the first year and finally 1 500 stems per hectare after the second year of growth (MacLennan & Jarmain 1990). Although the soil invertebrate pest species richness remained similar to other windrowed and burnt sites that were planted at a wider spacing, there was about a two and a half fold decrease in the incidence of soil invertebrate pest damage when seedlings were planted at a closer row spacing. The role of spacing and plant density in insect control depends on the crop, the types of insects and other factors that are not clearly understood (Kumar 1984). Generally though, an increase in plant density appears to reduce pest numbers, especially pests that are early colonizers of disturbed ground or patchy vegetation (Dent 1991). Although the yields of short rotation crops are negatively affected by an increase in plant density (Dent 1991), wattle is thinned at one and two years after planting, which would negate any yield loss during its ten year rotation cycle. Closer row spacing results in earlier canopy closure and hence a reduction of weeding operations. This also permits a greater degree of selection during thinning operations (Sherry 1952).

The old arable land site, that was adjacent to a sugarcane field, had an unusually large incidence of nematode damage. Both sugarcane and wattle are hosts to similar parasitic nematode species that gradually increase in population numbers to damaging levels when these crops are grown repeatedly on the same sites (Kleynhans *et al.* 1996). Nematodes inhibit root growth; some species cause root galls while other species cause root lesions, root necrosis and terminal thickening of the roots (Govender 1993). The damage and decrease in the fine root mass (on which whitegrubs feed) of nematode damaged wattle seedlings could probably explain the lower incidence of whitegrub damage in this windrow and burn plantation residue management regime.

Existing recommendations for the management of harvest residue in wattle plantations therefore needs to be reexamined with a view to decreasing the incidence of soil invertebrate pest damage. There should be a shift away from burning, especially the intense fires associated with the burning of windrows (Norris 1995) and a retention of the practice of minimal tillage (pitting, shallow ripping or ploughing) in regeneration sites (Hendrick 1979; van Goor 1985). Broadcasting of the plantation residue at clearfelling overcomes most of the disadvantages associated with burning. Compaction caused by heavy harvesting machinery is reduced when machines travel over plantation residue (Smith 2000; Smith *et al.* 2000a). The mulch layers reduces the germination of weeds, soil water runoff, direct evaporation from the soil surface, soil erosion and improves water infiltration (Norris 1995). The reduction in weeds because of not burning and broadcasting of the plantation residue has been shown to reduce most soil invertebrate pests except whitegrubs, nematodes and, to a limited extent, millipedes. However, the inclusion of shallow ripping decreased the numbers of whitegrubs and millipedes. An implement (coulter ripper), which consists of a hydraulically driven cutting wheel in front of a ripping tine, has been successfully used to manage broadcast plantation residue (Norris 1995). During tillage, harvest residues are also cut and incorporated into the soil. Decomposition of organic matter promotes the build up of nematophagous fungi and predatory nematodes that can suppress parasitic nematode populations (Kleynhans *et al.* 1996).

Coulter ripping should preferably be done along the contour and would depend on the terrain (Norris 1995). It is possible to perform this operation on a maximum slope of 11 degrees (13% to 20%), but with a crawler tractor one can attempt slopes of up to 40%. Average terrain would take about 1 hour/ha with a 60 kW tractor and although one is restricted to interrow planting this does not appear to be a problem in wattle because stumps decompose before the next rotation (Craig Norris, personal communication). The total cost of coulter ripping which includes diesel, tractor, ripping equipment, running costs, labour, depreciation of equipment, marking and loosening of the soil is about R110/hr (Craig Norris, 2001, personal communication). If sites outside of the coulter ripper range are regenerated to wattle, one has the option of preventatively treating seedlings with an insecticide during planting. Deltamethrin 5% SC at a rate of 0.025 g a.i./seedling (equivalent to 55.55 g a.i./ha for wattle at 2222 stems/ha) is registered for use against both whitegrubs and cutworms in forestry (Govender 1995; Nel *et al.* 2001). This costs about R236/ha (excluding labour) (Farmers Agricare, 2001, personal communication). The preventative use of insecticides, however, contravenes the Forest Stewardship Council guidelines and should be avoided (Govender, 2002).

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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.

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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.

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CHAPTER 7

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

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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.

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CHAPTER 8

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

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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.

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