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Sirex noctilio control program in response to the 1987 Green Triangle outbreak

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Summary

In 1987, 1.8 million tree deaths resulted from a *Sirex noctilio* outbreak in *Pinus radiata* plantations in southeastern South Australia and southwestern Victoria. The major response was to inoculate 147 000 trees with the parasitic nematode *Deladenus siricidicola*. Also, projects to salvage sirex-infested trees and to release the parasitoid *Megarhyssa nortoni* were implemented. The inoculation program cost $1.3 million. Productivity and costs were calculated for the seven procedures used to introduce the nematode. Efficiency was increased by using machines to fell and delimb the trees and by redesigning the inoculation hammer. Knowledge gained from this outbreak should prompt a review of the control recommendations. Forest managers should implement a rigorous control program, as soon as sirex is detected in a region, to minimise the risk of a future outbreak. Key words: *Sirex noctilio, Deladenus siricidicola*, biological control, forest pest management, *Pinus radiata*.

Introduction

Serious levels of tree mortality were observed in southeastern South Australia and southwestern Victoria in April 1987. This region, known as the "Green Triangle" (GT), had 113 000 ha of *Pinus radiata* D. Don plantations (Figure 1). Aerial observations confirmed that tree mortality was resulting in significant losses across the GT. The causal agent was identified as *Sirex noctilio* F., and an intensive control program was implemented during the winter of 1987.

The history of sirex in the GT and control projects prior to this outbreak have been reviewed (Haugen 1990). Major forestry organisations in the GT were:

- Woods and Forests Department of South Australia (W&F), 47 000 ha;
- Southern Australia Perpetual Forests Ltd.[1] (SAPFOR), 23 000 ha;
- Softwood Holdings Ltd.[2] (SHL), 18 000 ha;
- Department of Conservation Forests and Lands[3] of Victoria (CFL), 16 000 ha; and
- South East Afforestation Services[1] (SEAS), 9 000 ha.

[1] SEAS acquired SAPFOR in 1988 and became SEAS-SAPFOR.
[2] Softwood Holdings Ltd. became CSR-Softwoods in 1988.
[3] CFL became Department of Conservation and Environment in 1990.

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Plantations were grouped geographically into 7 GT-Divisions to summarise the sirex data (Figure 1).

This paper describes the sirex control program implemented, new techniques and equipment developed, and costs incurred.

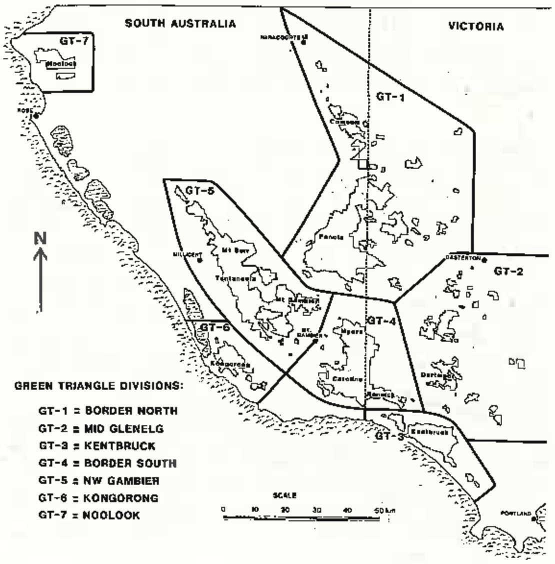


Figure 1. Pine plantations in the Green Triangle region of South Australia and Victoria.

Development of objectives

Representatives of the five forestry organisations met in May 1987 to discuss the sirex outbreak and control options. A preliminary estimate of 1 million sirex-associated tree deaths in the GT was made. Available evidence indicated that *Ibalia leucospoides* (Hochenwarth) was established in most plantations, but the other parasitoids, *Megarhyssa nortoni* (Cresson), *Rhyssa hoferi* Rohwer, *Rhyssa persuasoria* (L.), and *Schlettererius cinctipes* (Cresson), were not established (Haugen 1990). Previous inoculations of the parasitic nematode, *Deladenus siricidicola* Bedding, were relatively few and widely scattered. In 1987, a limited examination of female sirex from uninoculated trees did not detect any nematode establishment (Haugen 1990). Consequently, populations of the biological control agents, especially *D. siricidicola*, were considered to be greatly deficient and unlikely to reduce sirex populations within the next 5 years.

The representatives decided to co-ordinate an intensive *D. siricidicola* inoculation program during 1987. This nematode was considered the key biological control agent of sirex in Tasmania (Bedding and Akhurst 1974, Taylor 1981) and eastern Victoria (Neumann and Morey 1984). The primary objective was to introduce the nematode throughout the GT in quantities likely to reduce tree mortality to an acceptable level by 1990. To achieve this, an inoculation target of 20% of the sirex-infested trees was proposed. A goal to inoculate 166 000 trees was set after each organisation assessed its available labour and equipment.

The second objective was to salvage sirex-infested trees where a reasonable economic return could be expected. In addition, rescheduling of thinning operations to compartments with greater levels of tree mortality was recommended.

The third objective was to release *M. nortoni*, *R. hoferi*, *R. persuasoria*, and *S. cinctipes* in suitable numbers to attain establishment throughout the GT. However, insectary cultures of these species had been discontinued by the breeding program of the Australian Forestry Council (AFC) Sirex Fund. *Megarhyssa nortoni* could be obtained by collecting in areas of known establishment, but the other three species were not readily available from field collections. A goal was set to release 1000 pairs of *M. nortoni* in the GT during November 1987.

The inoculation program

Each organisation set weekly inoculation goals to allocate labour resources and to co-ordinate the supply of nematodes. An average of 3300 trees had to be cut and inoculated each day to meet the goal. Operational procedures and their productivity were unknown for this scale of inoculation, since previous programs were a maximum of 1000 trees per year (Neumann *et al.* 1987, Taylor 1981, Zondag 1979).

Each organisation directed the operations in its own plantations according to the following schedule:

(1) Aerial assessment of tree mortality by experienced observers.

(2) Ground assessment of tree mortality in sample compartment by forest workers and technical assistants.

(3) Decision on procedure and level of inoculation by forest managers and harvesting officers.

(4) Tree marking for machine operations or salvage logging by trained forest workers.

(5) Tree felling for inoculation, salvage, or billets by felling contractors and chainsaw operators.

(6) Inoculation by forest workers.

Tree mortality surveys

Sirex infestation levels were classified as low (< 5% tree mortality), moderate (5–10%), high (10–30%), or severe (> 30%) by subjective aerial observations from an aeroplane. Ground surveys checked the accuracy of these observations and indicated that the aerial observations were not always reliable. Inoculation goals were assigned to each locality based on these surveys.

Alternative procedures

A uniform inoculation prescription was not appropriate because sirex levels were highly variable and plantations differed in silvicultural history. Seven procedures to categorise various tree felling and inoculation operations were defined, along with a guide to assign these procedures to compartments (Table 1).

(1) Mechanical felling, whole-tree inoculation.

Mechanical tree felling was generally limited to thinned compartments with greater than 3% recent tree mortality.

(2) Chainsaw felling, whole-tree inoculation.

Trees were felled and delimbed using a chainsaw, generally where mechanical felling was not productive (e.g. stands with low levels of sirex).

(3) Intermittent thinning and whole-tree inoculation.

Commercial intermittent thinning (e.g., removal of every fortieth row and thinning of the 4 adjacent rows) was used to provide machine access into unthinned compartments. Sirex-attacked trees adjacent to the extraction rows were cut and inoculated.

(4) Inoculation of whole trees along compartment edges.

Sirex-attacked trees along compartment edges were felled and inoculated in compartments with poor internal access (e.g., non-commercially thinned compartments).

(5) Billets.

Inoculated billets (5 m long logs cut from sirex-infested trees) were transported to non-commercially thinned and unthinned compartments. Two billets were considered equivalent to one tree.

(6) Residual tops.

Residual tops resulting from sawlog salvage were delimbed and inoculated. Two inoculated tops were considered equivalent to one tree.

(7) Trap trees for 1988.

Trap trees (see Neumann *et al.* 1982) were established in localities that did not receive inoculations in 1987. Plots were established in November 1987 for inoculation during 1988.

Table 1. Guide for assigning inoculation procedures to compartments.

Access[1]	Sirex[2] Level	Procedure
T	> 3%	Salvage (if > 20 years old), or mechanical tree felling for inoculation
	0.5–3%	Chainsaw felling for inoculation
	< 0.5%	Chainsaw felling for inoculation, or no inoculation
UT	> 10%	Intermittent commercial thinning, then mechanical or chainsaw felling of sirex-infested trees for inoculation
	1–10%	Chainsaw felling for inoculation, or add inoculated billets
	< 1%	Establish trap trees to be inoculated in 1988
NCT	> 10%	Add billets, and inoculate along compartment edges
	1–10%	Add billets
	< 1%	Establish trap trees to be inoculated in 1988

[1] T = thinned, UT = unthinned, NCT = non-commercially thinned.

[2] per cent tree mortality for 1987.

Tree felling and delimbing

Felling and delimbing of trees for inoculation were major constraints of the program. Mechanical tree felling was done primarily with the Hydro-Ax®. Two machines were fitted with felling heads (Figure 2a), and a third machine was fitted with a slasher head for delimbing (Figure 2b). A John Deere Harvester® also was used for tree felling and billet production (Figure 2c).

(a)

(b)

(c)

Figure 2. Hydro-Ax with (a) cutting head and (b) slashing head; (c) John Deer Harvester.

Delimbing of trees was necessary to provide safe and productive access to the entire length of the bole for inoculation. Mechanical log delimbers normally used in harvesting operations were unsuitable because they removed substantial proportions of bark. Partially debarked logs were expected to have lower moisture contents, and thus lower rates of infection by the nematode (Bedding and Akhurst 1974).

Nematode inoculation

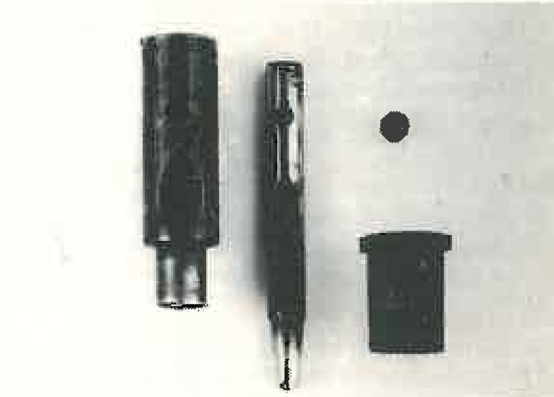
The most favourable period for inoculation with nematodes is considered to be May to August (Neumann *et al.* 1987). Inoculations during 1987 could not begin until late July, and completion was scheduled for 1 October. Thus, the percentage of sirex infected with nematodes in inoculated trees was expected to be less than the 97–99% attained by Bedding and Akhurst (1974).

Nematodes were produced by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) — Division of Entomology in Hobart, Tasmania, and by the Keith Turnbull Research Institute (KTRI) of CFL in Melbourne, Victoria. A total of 20 billion (2.0 x 10^{10}) nematodes were needed during the 10 weeks of this inoculation program.

Nematodes were mixed into an aerated foam, prepared from a 6% gelatin solution (Neumann *et al.* 1987). A 6 L mixture with 5 million nematodes was sufficient to inoculate 50–70 trees at the rate of 1000 nematodes per inoculation hole. Since inoculations during 1986 resulted in only 16–18% of female sirex infected with the nematode (Haugen 1990), nematode handling and inoculation procedures were scrutinised after each step to ensure nematode survival.

Sirex-attacked trees were inoculated by punching holes, 7 mm in diameter and 7-10 mm deep into the sapwood, and filling these holes with inoculum. The Gould punch had been used previously (Bedding and Akhurst 1974, Neumann *et al.* 1987), however a more efficient tool was needed for this program. The "SWAT" (Sirex Wasp Assault Team) inoculation hammer was designed, which included a rebound rubber, an ergonomic handle, and an easily replaceable wad punch (Figure 3). The 50 ml plastic syringe, used in previous years to inject inoculum into holes (Bedding and Akhurst 1974), was replaced with a 250 ml plastic sauce bottle (Bipa Products®) fitted with a pipette tip. The sauce bottle was easier to use, caused less hand strain, and held more inoculum.

(a)



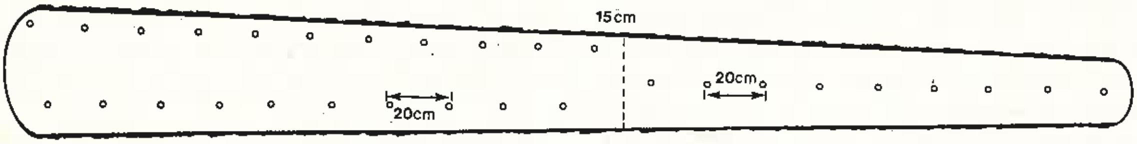
(b)

Figure 3. (a) SWAT inoculation hammer (top) and Gould punch (bottom); (b) close up of disassembled SWAT hammer with wad punch and rebound rubber.

Inoculation holes were spaced 20 cm apart, closer than previous recommendations of 30 cm (Bedding and Akhurst 1974), and 30–40 cm (Neumann *et al.* 1987). This shorter spacing was done to compensate for the lateness of the inoculations and the low moisture content of the sirex-attacked trees (generally 30–40% of dry weight). Trees were inoculated along the bole from the base to a 5 cm diameter top. Where the bole was greater than 15 cm in diameter, two rows of inoculation holes were made (Figure 4).

Nematode inoculation was discontinued on days when the maximum temperature was predicted to exceed 20°C. The gelatin foam tended to collapse and liquefy above this temperature. Nematode movement from the inoculum into the tracheids was presumed to be greatly reduced under these conditions.

(a)



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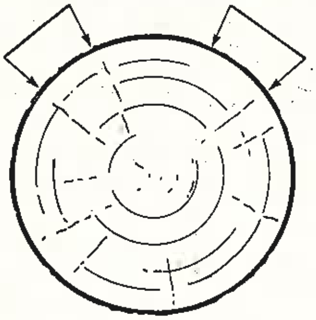

Figure 4. Schematic diagram indicating position of inoculation holes in a tree; (a) top view, (b) end view, with brackets denoting locations for the double row.

Billets

Billet production was limited to a few compartments with high to severe sirex infestations and acceptable transport distances. Also, salvage operations produced billets from the normal pulpwood component. Billets were inoculated, transported to their destination, and distributed around compartment perimeters.

Results

Tree mortality

Data from aerial and ground surveys provided estimates of tree mortality in infested compartments in 1987, and these data were summarised by GT-Division (Table 2). Compartments with high and severe infestations (> 10% tree mortality in 1987) totalled 1929 ha. For comparison, the Delatite outbreak in Victoria had 561 ha in the > 15% cumulative mortality categories at the end of the outbreak (McKimm and Walls 1980). Compartments in the moderate category (9496 ha with 5–10% mortality) represented a great potential for high or severe damage in 1988. Compartments in the low infestation category (< 5% mortality) were likely to sustain greater damage in 1988 and 1989, particularly if the environmental conditions are favourable for increases in the sirex population.

Table 2. Sirex infestations in the Green Triangle during 1987 by number of recent tree deaths, and by area (ha) in each damage class.

		Damage Classes[2]				
GT-Division	Deaths[1]	low < 5%	moderate 5–10%	high 10–30%	severe > 30%	Total[3]
1—Border North	74950	12175	369	35	0	12579
2—Mid Glenelg	46350	7069	91	0	0	7160
3—Kentbruck	390300	6674	2917	393	46	10030
4—Border South	803000	7397	4279	1305	73	13054
5—NW Gambier	239100	5668	1234	68	9	6979
6—Kongorong	177800	3489	606	0	0	4095
7—Noolook	18900	3012	0	0	0	3012
Total	1750400	45484	9496	1801	128	56909
% of Total		79.9	16.7	3.2	0.2	

[1] number of sirex-associated tree deaths.
[2] per cent tree mortality.
[3] area of 10–30 year old pine plantations.

Nematode inoculation (Objective One)

Approximately 147 000 trees were inoculated with nematodes (Table 3), which was 89% of the goal. Whole-tree inoculations comprised 79% of the total, while billets, residual tops, and trap trees accounted for 14%, 6%, and 1%, respectively. Inoculating 20% of the sirex-attacked trees in every compartment was not feasible. Compromises had to be made between maintaining productivity and achieving geographic distribution. The actual proportion inoculated in a locality varied with the sirex level, the inoculation productivity, and the number of trees inoculated in adjacent localities. Generally, compartments in the moderate to severe damage classes (> 5% tree mortality) had 5–20% of the trees inoculated. Localities in the low damage class were either inoculated (approximately 20% of sirex-infested trees) or scheduled for trap tree establishment (and subsequent inoculation in 1988).

The total cost of the inoculation program for 1987 was $1.3 million (Table 4). Productivity and costs of the various operations were estimated (Table 5). The cost to fell and inoculate a tree was generally $6.00 to $7.00. Felling and delimbing were 50–60% of this cost. Inoculation productivity was generally 30–35 trees per worker-day, with a maximum rate of 50–60 trees per worker-day. The cost of billets was $9.00 to $10.00 per tree equivalent. Nematodes and inoculation supplies were calculated to be $0.33 per inoculated tree (Table 6.).

Salvage (Objective Two)

Salvage operations were generally restricted to thinned compartment with trees > 35 cm dbh and with yields of > 20 m^3/ha. A total of 1483 ha were salvaged and produced 38 000 m^3 of sawlogs and 12 500 m^3 of pulpwood. In addition, thinning operations were relocated into compartments with greater levels of tree mortality as a hygiene/salvage operation.

Products from salvaged sawlogs were inferior in quality. The highly variable moisture content among salvaged sawlogs resulted in kiln-dried products below the acceptable moisture content.

Rough surfaces and ring shakes were more prevalent in products from sirex-infested logs. Appearance defects, such as zone lines and reactions with varnish, were associated with the symbiotic fungus, *Amylostereum areolatum* (Fr.) Boidin. Sawlogs salvaged in spring had conspicuous larval galleries that downgraded sawn products.

Pulpwood from sirex-infested trees had a higher resin content (infested = 2.2% resin on dry wood, normal = 1.8%) (Apcel Inc., Millicent SA, unpublished data). The higher resin content increased chemical use and produced sediments on machinery. Also, the monetary return to the grower for infested trees was less because pulpwood is sold by weight, not volume.

Salvaged trees were used to produce CCA-treated products (a vacuum-pressure treatment with copper-chromium-arsenate preservative). Sirex emergence was recorded from properly CCA-treated posts (Woods & Forests, unpublished data). Use of salvaged trees for CCA-treated products should be reviewed to consider the potential impact on the commercial industry and the risk of sirex transfer to uninfested regions.

Table 3. Nematode inoculations during 1987 in the Green Triangle.

GT-Division	Number of Tree Equivalents Inoculated WT[1]	TT[2]	BS[3]	BD[4]	RT[5]	TOTAL	TT-88[6]
1—Border North	8482	372	1524	2364	405	11623	2301
2—Mid Glenelg	1888	185	0	350	0	2423	1957
3—Kentbruck	22770	71	0	194	0	23035	4785
4—Border South	47695	225	14927	5906	8009	61835	8337
5—NW Gambier	24649	317	3296	7845	0	32811	3432
6—Kongorong	5471	20	800	3888	117	9496	768
7—Noolook	5420	79	0	0	0	5499	260
Total	116375	1269	20547	20547	8531	146722	21840

[1] whole trees; cut and inoculated within the compartment.
[2] trap trees (established in 1986).
[3] billets source (2 billets = 1 tree equivalent).
[4] billets destination.
[5] residual tops (2 tops = 1 tree equivalent).
[6] number of trap trees established in 1987 (for inoculation in 1988).

Table 4. Cost of nematode inoculation program during 1987.

Component	Unit Cost[1]	No. Trees	Total Cost[2]
Aerial Survey			$ 11,000
Ground Survey			$ 20,000
Tree Marking	$0.80	60,700	$ 49,000
Tree Felling			
— machine	$2.50	60,700	$152,000
— chainsaw	$4.20	57,300	$241,000
Whole-Tree Inoculation	$3.10	118,000	$366,000
Billets	$9.80	20,500	$201,000
Residual Tops	$6.00	8,500	$ 51,000
Nematodes			$ 38,000
Inoculation Supplies			$ 10,000
Inoculum Mixing			$ 27,000
Supervision/ Administration			$150,000
Vehicle Costs			$ 12,000
Miscellaneous Supplies			$ 10,000
Total			$1,338,000

[1] per tree or tree equivalent.
[2] includes overheads.

Table 5. Productivity and costs of nematode inoculations.

Procedure	Productivity[1]	Unit Cost
WHOLE TREE — MACHINE		
Tree Marking	120–170 T/WD	$0.60–0.85/T
Tree Felling		
— Hydro-Ax	40 T/MH	$2.20/T
— JD Harvester	50–75 T/MH	$2.00–3.00/T
Inoculation	25–60 T/WD	$1.67–4.00/T
Total		$4.27–7.85/T
WHOLE TREE — CHAINSAW		
Tree Felling		
(> 5% mortality)		
— hourly rate	30–50 T/WD	$2.00–3.33/T
— contract	80–120 T/WD	$1.20–2.00/T
(0.5–5% mortality)		
— hourly rate	15–30 T/WD	$3.33–6.67/T
Inoculation	25–60 T/WD	$1.67–4.00/T
Total		$3.67–10.67/T
BILLETS		
Felling/Cutting	80–120 TE/MH	$2.00–3.80/TE
Inoculation	50 TE/WD	$2.00/TE
Extraction	30 TE/MH	$1.60/TE
Transport	normal rates	$1.00/TE
Distribution	25 TE/MH	$2.00/TE
Total		$8.60–10.40/TE
RESIDUAL TOPS		
Delimb/Inoc.	15–20 TE/WD	$5.00–6.67/TE
TRAP TREES		
Establishment	40–60 T/WD	$2.50–3.00/T
Fell/Delimb/Inoc.	25–40 T/WD	$2.50–4.00/T
Total		$5.00–7.00/T

[1] T = tree, TE = tree equivalent, MH = machine hour, WD = worker day.

Table 6. Cost of nematodes and inoculation supplies.

	Amount	Unit Cost	Cost
NEMATODES			
CSIRO	18,086 million	$1.50/million	$27,200
shipping	21 shipments	$0.13/million	$ 2,290
KTRI	822 million	$9.62/million	$ 7,910
shipping	14 shipments	$0.55/million	$ 450
Total	147,000 trees	$0.26/tree	$37,850
INOCULATION SUPPLIES			
Gelatin	100 kg	$0.60/kg	$ 60
Mixers	8	$400.00/mixer	$ 3,200
SWAT Hammers	100	$14.00/hammer	$ 1,400
Wad Punches	367	$11.90/punch	$ 4,370
Rebound Rubbers	667	$1.50/rubber	$ 1,000
Sauce Bottles	400	$0.40/bottle	$ 160
Total	147,000 trees	$0.07/tree	$10,190

Parasitoid release (Objective Three)

A total of 2247 *M. nortoni* (1295 males, 952 females) were released, which was equivalent to all previus *M. nortoni* releases in the GT (Haugen 1990). Releases of 25–50 pairs were made into compartments with > 5% tree mortality. The 35 release sites were widely distributed within six of the GT-Divisions. More releases of *M. nortoni* are needed to attain establishment in all sirex-infested localities throughout the GT.

Discussion

The royalty value of the trees killed during 1987 was estimated at $5–6 million. However, the impact of this sirex outbreak on the long-term management and future availability of wood resources can not be evaluated fully until the outbreak declines and the cumulative stand damage is assessed.

The success of these nematode inoculations in controlling sirex populations and reducing tree mortality needs to be evaluated during the next 3–5 years. A program has been designed to evaluate nematode infection rates in inoculated and uninoculated trees. This information is vital to plan future inoculations and to assess the increase in infection levels over time. This evaluation program also will survey for parasitoid establishment within the GT.

This sirex outbreak and the cost of the control program should provide the impetus for forest managers to implement a rigorous control program. A control program should begin as soon as sirex is detected in a region, instead of waiting until economic damage occurs. Further research is needed to expand and revise the current recommendations, especially for nematode introductions, sirex monitoring, and parasitoid introduction.

Acknowledgements

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