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Control procedures for Sirex noctilio *in the Green Triangle: Review from detection to severe outbreak (1977-1987)*

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Summary

Procedures for the control of *Sirex noctilio* are described for the *Pinus radiata* plantations of southeastern South Australia and southwestern Victoria. Sirex was detected in this region during 1977, and a major outbreak occurred in 1987. Limitations of these procedures in providing adequate control are discussed. To reduce the risk of an outbreak, managers need to: 1) follow an optimum thinning schedule to maintain stand vigour, 2) accurately monitor sirex populations, 3) introduce biological control agents at the appropriate time and levels, and 4) evaluate the distributions and population levels of the biological control agents.

Key Words: *Sirex noctilio,* biological control, forest pest management, pest surveys, *Deladenus siricidicola.*

Introduction

Sirex noctilio Fabricius, commonly called sirex wasp or sirex, has been a major insect pest of *Pinus radiata* D. Don plantations in Australia since the 1950s. A great increase in sirex-associated tree mortality was observed during April 1987 in the *P. radiata* plantations of southeastern South Australia and southwestern Victoria (Figure 1). This region, known as the Green Triangle (GT), has 113 000 ha of *P. radiata* plantations, and these plantations are managed by five forestry organisations:

- Woods and Forests Department of South Australia (W&F), 41% of GT plantations;
- Southern Australia Perpetual Forests Ltd.[1] (SAPFOR), 21% of GT plantations;
- Softwood Holdings Ltd.[2] (SHL), 16% of GT plantations;
- Department of Conservation, Forests and Lands[3] of Victoria (CFL), 14% of GT plantations; and
- South East Afforestation Service Pty. Ltd.[1] (SEAS), 8% of GT plantations.

Each organisation has plantations in a number of locations within the GT, and many plantations have common boundaries with plantations of different ownership. For the summary of sirex data, these plantations have been grouped into seven GT-Divisions (Figure 1).

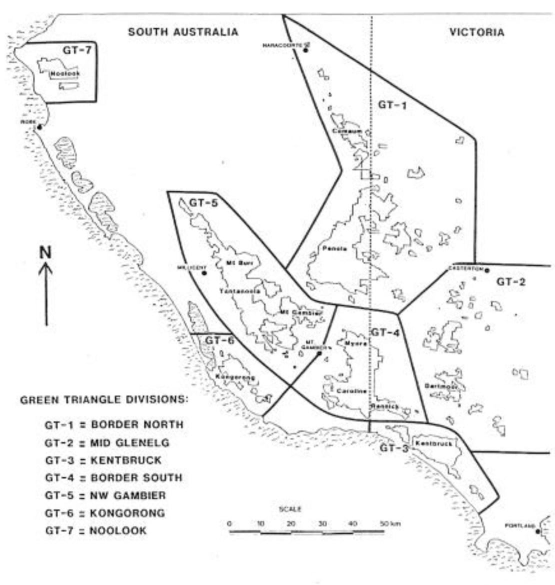

Figure 1. Pine plantations in the Green Triangle region of South Australia and Victoria.

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

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During May 1987, initial ground counts revealed 30–50% sirex-associated tree mortality in a few sample compartments, while others were in the 5–10% or 10–30% categories. The most significant damage was to 10–22 year-old plantations located in GT-4 and GT-3. An initial estimate of 1 million sirex-associated tree deaths was made from limited aerial and ground observations. This is the largest sirex outbreak recorded in Australia, and it has the potential to increase and spread throughout the GT over the next few years.

Objectives of this paper are to:

- document the sirex control procedures used in the GT from 1977–1987,
- consider their limitations in providing adequate sirex control, and
- discuss the need for a more rigorous sirex control program.

Major topics presented under each objective are sirex monitoring, silvicultural control, biological control, and evaluation of biological control agents. The control procedures described in this paper are a collective representation from the GT organisations, while the specific details are based on W&F procedures.

Overview of Sirex in Australia

Sirex noctilio is native to Europe, but it rarely causes significant tree mortality there (Spradbery and Kirk 1978). After it was accidentally introduced into New Zealand (Miller and Clark 1935), epidemic outbreaks developed (Rawlings 1955). Sirex was discovered near Hobart during 1952 and then near Melbourne during 1961. Localized outbreaks occurred in Tasmania (Madden 1975) and eastern Victoria (McKimm and Walls 1980).

Biological control was considered to have a high potential for success in Australia because sirex rarely causes damage in its native range. Two species of parasitoids, *Rhyssa persuasoria* (L.) and *Ibalia leucospoides* (Hochenwarth) were introduced into Tasmania during 1957–1960 (Taylor 1967). A world-wide search for natural enemies of siricids was conducted during 1962 –1973, and 21 species of parasitoids were imported. Ten of these species were released in Tasmania and five species became established (Taylor 1976).

A parasitic nematode of sirex, *Deladenus siricidicola* Bedding, was discovered during 1962 in New Zealand (Zondag 1969). Techniques to mass-rear *D. siricidicola* in laboratory cultures and to artificially inoculate sirex-infested trees were developed by Bedding and Akhurst (1974). A trap tree technique was developed (Neumann *et al.* 1982) that increased the efficiency of nematode introduction into low sirex populations.

Information on sirex biology, sirex-tree interactions, the associated fungus, biological control agents, and sirex control procedures have been reviewed by Taylor (1981), Neumann *et al.* (1987), and Madden (1988).

Procedures Used Prior to 1987 for Sirex Control

Sirex Monitoring

A sirex detection program for the GT began soon after sirex was discovered in eastern Victoria during 1961. Locations of dying trees were mapped from fixed-wing aircraft during October of each year; then ground checks were used to determine the presence of sirex in a sample of these trees. Sirex was discovered in the GT during November 1977 at the SHL-Dartmoor district (GT-2), then at W&F-Penola and W&F-Comaum districts (GT-1) during 1980. These detections were not the result of formal ground checks, but by forest personnel observing exit holes and adults during normal field duties. By 1982, sirex had been detected in every GT-Division, except GT-7 (Noolook).

Woods & Forests personnel ground checked 50–180 compartments per year for the presence of sirex (100–250 trees). Recently dead trees were felled, and sections along the bole were sampled to detect larvae and larval galleries. These data show an increase in sirex positive compartments from 1980 to 1986 (Table 1). Sirex detections notably increased at W&F-Myora district in the 1983 survey. This trend became more evident during 1984 at Caroline, Mt. Gambier, Tantanoola, and Penola districts.

Prior to 1986, only single tree deaths or "scattered deaths" were observed in compartments during aerial observations. However during 1986, 76 W&F compartments showed more than "scattered deaths" and were categorized as having 2–10% or 11–20% tree mortality. These compartments were in 15 localities distributed over four districts, with 839 ha in the 2–10% category and 60 ha in the 11–20% category (W&F Sirex Report — August 1987, unpublished). No ground surveys were done to verify the accuracy of these aerial observations.

Table 1. Number of compartments sampled during ground checks to detect sirex (No. sirex positive/No. sampled) in W&F plantations from 1980 to 1986 (W&F unpublished data).

GT Division	W&F District	1980	1981	1982	1983	1984	1985	1986
GT-1	Comaum	1/4	0/6	0/4	0/10	2/6	5/10	7/10
GT-1	Penola	1/9	2/5	1/6	1/8	18/32	5/15	21/23
GT-4	Myora	0/3	1/12	0/4	6/7	5/8	39/41	21/21
GT-4	Caroline	0/9	0/5	0/5	1/2	3/4	11/12	19/20
GT-5	Mt. Gambier	0/6	0/10	0/7	1/2	9/15	23/30	15/15
GT-5	Tantanoola	0/4	0/8	0/7	2/14	5/10	27/33	28/29
GT-5	Mt. Burr	0/4	0/7	0/9	0	1/23	9/17	9/9
GT-6	Kongorong	0/2	0/1	0/5	0	0/1	3/6	3/3
GT-7	Noolook	0/8	0/4	0/5	0/8	0/1	0/14	10/12
Total		2/49	3/58	1/52	11/51	43/100	122/178	133/142
% Positive		4	5	2	22	43	69	94

Silvicultural Control

Neumann (1979) suggested silvicultural measures as an approach for preventative control of pests in pine plantations. Specific recommendations (Neumann *et al.* 1987) for sirex control included:

- thin stands on time to reduce inter-tree competition and to remove suppressed, multi-stemmed, and damaged trees;
- restrict non-commercial thinning and high pruning operations to periods outside the sirex flight season;
- avoid planting on steep slopes where thinning cannot be carried out;
- minimise injuries to trees from silvicultural treatments, or other preventable causes;
- salvage trees damaged by fire, wind, lightning, or other natural causes.

Silvicultural practices were not significantly modified after the detection of sirex in the GT. In June 1987, 16% (9 300 ha) of the 10–30 year-old plantations were past the optimum thinning range (Lewis *et al.* 1976) by more than 5 years, especially unthinned stands overdue for first thinning. Also, thinning and pruning operations were not restricted to periods outside the flight season.

Biological Control

Deladenus siricidicola. Inoculations of *D. siricidicola* in the GT began in 1980 (Table 2) using naturally attacked trees (i.e., trees which had not been injected with herbicide). Two trap tree plots were established in 1980, but these trees were not attacked by sirex. No further nematode inoculations were made from 1982 to 1984. During 1985, 194 trap trees were inoculated (28 plots), followed by the inoculation of 997 trap trees (145 plots) and 121 naturally attacked trees during 1986.

Parasitoids. Releases of sirex parasitoids began in the GT during 1977 and five species have been released. Release data to May 1987 are summarised in Tables 3, 4 and 5. *Ibalia leucospoides* accounted for 94% of the total female parasitoids released in the GT (Table 3). The mean number of female *I. leucospoides* per release site varied greatly among

Table 2. Number of trees inoculated with *Deladenus siricidicola*, by Green Triangle Division.

GT-Division	Area[1] (ha)	Year of inoculation 1980	1981	1982	1983	1984	1985	1986
1—Border North	12579	0	2	0	0	0	73	302
2—Mid Glenelg	7160	25	13	0	0	0	0	149
3—Kentbruck	10030	0	1	0	0	0	0	60
4—Border South	13054	0	0	0	0	0	7	253
5—NW Gambier	6979	0	0	0	0	0	48	278
6—Kongorong	4095	0	0	0	0	0	66	76
7—Noolook	3012	0	0	0	0	0	0	0
Total	56909	25	16	0	0	0	194	1118

[1] Area of 10–30 year old pine plantations in 1987.

the years (Table 4). Even within a year, the number of females released at each site was extremely variable. Releases of *I. leucospoides* were well distributed among GT-Divisions (Table 5). However, once these sites were mapped during 1987, clumping of release sites within the GT-Divisons became evident. Also, releases were frequently made into the same or adjacent compartments over successive years.

Releases of *Megarhyssa nortoni* (Cresson) were sporadic and very limited compared to releases of *I. leucospoides* (Table 3), but the mean number of female *M. nortoni* per release site was consistent (Table 4). *Rhyssa hoferi* Rohwer, *R. persuasoria*, and *Schlettererius cinctipes* (Cresson) were released at 2, 15, and 8 sites, respectively (Table 3). *Rhyssa hoferi* was particularly sought during collections in North America because it is native to a drier climate than the other species. Releases of *R. hoferi* were recommended for South Australia and Western Australia (Taylor 1976). However, only 2 releases have been made in the GT (Table 3), even though *R. hoferi* bred satisfactorily in captivity (Neumann *et al.* 1987).

Evaluation of Biological Control Agents

Deladenus siricidicola. Sample logs from trap trees inoculated in 1985 and 1986 were collected to determine the success of these inoculations. Female sirex emerging from the caged logs were dissected

Table 3. Parasitoid releases for each species[1] by (a) the number of sites and (b) the number of females released[2] in the Green Triangle to May 1987.

(a)	Number of release sites by year[3]											
Spp.	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	Total
IL	0	5	1	5	8	6	16	19	11	39	62	172
MN	1	3	0	5	1	3	6	0	18	4	*	41
RH	0	0	0	1	0	1	0	0	0	0	*	2
RP	0	2	0	4	0	0	0	0	7	2	*	15
SC	0	0	0	0	0	1	0	0	5	2	*	8
(b)	Number of female parasitoids released by year[3]											
Spp.	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	Total
IL	0	718	206	547	2642	1247	2792	2126	1799	9265	1954	23296
MN	38	85	0	106	18	100	155	0	489	108	*	1099
RH	0	0	0	14	0	18	0	0	0	0	*	32
RP	0	38	0	74	0	0	0	0	161	20	*	293
SC	0	0	0	0	0	18	0	0	90	27	*	135

[1] IL = *Ibalia leucospoides*
MN = *Megarhyssa nortoni*
RH = *Rhyssa hoferi*
RP = *Rhyssa persuasoria*
SC = *Schlettererius cinctipes*

[2] Males released with females, usually in equal or greater numbers than females.

[3] * = not applicable, release period during September-December.

Table 4. Number of *Ibalia leucospoides* and *Megarhyssa nortoni* females released per site, mean and range[1], in the Green Triangle by year to May 1987.

	1977	1978	1979	1890	1981	1982	1983	1984	1985	1986	1987
I. leucospoides											
Mean	N	144	206	109	330	208	175	112	164	238	32
Maximum	N	225	206	149	675	369	399	198	299	767	62
Minimum	N	104	206	71	147	112	46	103	90	15	4
M. nortoni											
Mean	38	28	N	21	18	33	26	N	27	27	*
Maximum	38	33	N	28	18	58	31	N	48	36	*
Minimum	38	26	N	13	18	16	24	N	6	10	*

[1] N = none released.
* = not applicable, release period during September-December.

to determine if nematodes were present. A preliminary summary for emergences during 1986 (inoculated in 1985) reported 38–85% nematode infection for five locations sampled in the GT (Australian Forestry Council 1986). An evaluation of the W&F trap trees inoculated in 1986 estimated 16–18% nematode infection (W&F Sirex Report — August 1987, unpublished). These results were inferior compared to the 97–99% infection rate obtained with the original inoculation procedure (Bedding and Akhurst 1974).

Parasitoids. Establishment of the parasitoids was evaluated for 1985 and 1986 by collecting sample logs from sirex-attacked trees "at random" from W&F districts. These logs were held in five insectary cages for a year, and insect emergences were recorded (Table 6) (W&F Sirex Report — August 1987, unpublished). From this evaluation, *I. leucospoides* was confirmed to be established in at least five districts, and *M. nortoni* was confirmed in at least two districts.

Limitations of this control program

After sirex was detected in the GT, the intention appears to have been one of "wait and see" if sirex was going to develop "high" populations before implementing a rigorous control program. The program adopted was inadequate to provide the detailed data needed to make informed decisions on sirex control. After sirex had been in the GT

Table 5. Number of release sites[1] for *Ibalia leucospoides* and *Megarhyssa nortoni* by Green Triangle Division to May 1987.

GT-Division	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	Total
I. leucospoides												
1—Border North	0	0	0	0	4	2	3	4	3	7	4	27
2—Mid Glenelg	0	5	1	5	2	1	2	0	1	1	7	25
3—Kentbruck	0	0	0	0	2	2	8	2	0	4	12	30
4—Border South	0	0	0	0	0	1	3	6	2	7	18	37
5—NW Gambier	0	0	0	0	0	0	0	7	3	6	14	30
6—Kongorong	0	0	0	0	0	0	0	0	2	14	2	18
7—Noolook	0	0	0	0	0	0	0	0	0	0	5	5
Total	0	5	1	5	8	6	16	19	11	39	62	172
M. nortoni												
1—Border North	0	0	0	2	0	1	1	0	7	2	*	13
2—Mid Glenelg	1	3	0	1	1	1	1	0	0	1	*	9
3—Kentbruk	0	0	0	2	0	0	0	0	0	0	*	2
4—Border South	0	0	0	0	0	1	3	0	1	1	*	6
5—NW Gambier	0	0	0	0	0	0	1	0	4	0	*	5
6—Kongorong	0	0	0	0	0	0	0	0	6	0	*	6
7—Noolook	0	0	0	0	0	0	0	0	0	0	*	0
Total	1	3	0	5	1	3	6	0	18	4	*	41

* = not applicable, release period during September-December.

Table 6. Emergence data by species[1] from sample logs[2] taken from trees attacked by sirex during 1985 and 1986 (W&F Sirex Report — August 1987, unpublished).

Cage	GT[3]	1985				1986			
		n	SN	IL	MN	n	SN	IL	MN
Penola/Comaum	GT-1	24	446	24	0	30	1552	400	0
Myora/Caroline	GT-4	28	2215	32	0	30	1808	401	1
Mt. Gambier	GT-5	26	1604	100	0	30	1248	153	0
Tantanoola	GT-5	21	1073	17	0	29	1491	319	3
Mt. Burr/Noolook	GT-5 & 7	26	950	2	0	26	924	238	0

[1] SN = *Sirex noctilio*
IL = *Ibalia leucospoides*
MN = *Megarhyssa nortoni.*

[2] n = number of 1 m long billets.

[3] Green Triangle Division.

for a number of years and no serious damage had occurred, the impression that "sirex would not be a problem in the GT" was generated, and complacency developed.

Sirex Monitoring

The major limitation of the GT monitoring program was the lack of sirex population data. The program continued to detect sirex, but did not quantify sirex impact or changes in sirex populations in specific compartments or localities. Annual changes in sirex populations were appraised by informal subjective inspections, and decisions on control procedures were based on these impressions.

The objectives and data interpretation of the ground checks were not detailed before data collection. The result was a data set (Table 1) that was difficult to analyse (e.g., the sampling design did not permit statistical comparisons between years). The number of compartments checked per district and their geographical distribution within a district appear to have been selected haphazardly. Compartments with previous sirex detections often were re-sampled in following years. This aspect of the sampling design confounded the data analyses and did not add data to map the sirex distribution.

Despite the haphazard nature of this detection program, evidence of sirex establishment was obtained in each GT-Division at least 5 years prior to the serious outbreak. However, this detection method should have been tested for its efficiency and accuracy. Suppressed and sub-dominant trees, which have the greatest likelihood of sirex attack at low sirex densities (Madden 1975, Neumann and Minko 1981), may not be readily visible from the air.

Silvicultural Control

Recommendations for silvicultural control of sirex were not implemented in the GT. This lack of action resulted in overstocked stands that were more susceptible to sirex. Sirex populations, unchecked by adequate populations of the biological control agents, were able to increase rapidly in these susceptible plantations.

Biological Control

Deladenus siricidicola. Bedding and Akhurst (1974) recommended nematode inoculations in the advancing front of sirex infestations. However, a concept that "high" sirex populations were needed to successfully establish the nematode prevailed in the GT (e.g., Woods & Forests 1985). Neumann and Morey (1984) recommended inoculation of trap tree plots on a 1 km grid through unthinned plantations of intermediate age for at least 2 consecutive years. Trap tree inoculations fell far short of this recommendation in all GT-Divisions (Table 2). In retrospect, nematode inoculations were inadequate to establish this key biological control agent throughout the GT in time to avert a severe outbreak.

Parasitoids. Parasitoid releases were limited by the supply from the National Sirex Parasitoid Breeding Program of the Australian Forestry Council (AFC). Supplies of *I. leucospoides* for field release were much greater than those for the other parasitoid species (Table 3). Insectary cultures of *I. leucospoides* started with more parent adults and produced more offspring for release (Neumann *et al.* 1987).

During 1985/1986, the insectary cultures were phased out (Australian Forestry Council 1987). Only *I. leucospoides* would be readily available for release after the cultures were terminated, as it was easily collected from field populations in eastern Victoria. Field populations of *M. nortoni, R. persuasoria*, and *S. cinctipes* have been detected, but their densities were considered too low to collect efficiently. A field population of *R. hoferi* had not been detected in Australia when the insectary culture was discontinued[4].

Data from the GT (Tables 3 and 4) indicate a haphazard approach to releasing parasitoids. No recommendations were found stating a minimum or optimum number of parasitoids to release at each site. Release of *I. leucospoides* varied greatly in the number of females per site (Table 4). For the other species, few females were released at each site (Table 3), which may have been too few to consistently achieve establishment of those species. Also, criteria for selecting release compartments were not documented, but the distribution of release sites suggests that widespread establishment within a GT-Division was not a major objective.

Evaluation of Biological Control Agents

The design of the GT evaluations produced data with limited use. Logs from many compartments throughout one or more districts were grouped into

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[4] In November 1988, *R. hoferi* establishment was confirmed in New South Wales and in the Green Triangle (SHL-Dartmoor).

a single emergence cage. Consequently, these emergence data (Table 6) were not suitable to map distributions within a district, or to select localities for future parasitoid releases. Nematode evaluations only quantified the average infection level from inoculated trap trees. Nematode transfer to uninoculated trees and geographic spread from inoculation plots were not investigated in the GT. Thus, distribution and infection levels of nematode were not examined, and this information was not available for planning additional inoculations.

Discussion of control procedures

Future control programs need to be carefully planned and rigorously implemented. Major components of a control program should be integrated, so results from one component can be used to make decisions when implementing other components (e.g., results from the monitoring component should be used to plan nematode inoculations and parasitoid releases, to select areas for evaluation, and to assign priorities to silvicultural operations).

Sirex monitoring

A monitoring program should provide data to map the sirex distribution within a region and to accurately quantify sirex-associated tree mortality in sample compartments. Initially, an efficient and reliable procedure to detect sirex establishment is required. Routine forest surveillance, by personnel trained to identify symptoms of sirex, is adequate when the risk of sirex introduction is low, but a system of trap tree plots is warranted when this risk increases.

Monitoring procedures and their intensity should change as the status of a sirex population (i.e., from initial detection to imminent outbreak). Procedures to monitor sirex populations at low levels (e.g., $< 0.5\%$ annual tree mortality) over large areas have not been suitable. Ground surveys, either by temporary transects or permanent plots, are time-consuming and numerous plots are required to produce a comprehensive survey. Aerial observations also appear to be unsuitable for low sirex populations. Trap trees have been suggested as a monitoring tool (Neumann *et al.* 1982), but a procedure for collecting and interpreting this type of data needs to be developed. Aerial photography with infrared film has been used to monitor outbreak populations (McKimm and Walls 1980), but it is an expensive procedure to monitor an entire forest region. Further studies are required to develop an accurate and cost-effective procedure for monitoring sirex populations, especially at low levels.

Silvicultural Control

Control of sirex by silvicultural methods has been widely recommended (e.g., Madden 1975, Neumann 1979, Taylor 1981, Neumann *et al.* 1987). Further investigations are needed to quantify the benefits of these silvicultural recommendations and to incorporate them into forest management plans. It is apparent that timely selective thinning reduces the risk of a sirex outbreak (e.g., McKimm and Walls 1980), but a hazard-rating system (see Hedden *et al.* 1981) for sirex needs to be developed to efficiently implement this recommendation.

Biological Control

A key factor in reducing the risk of a sirex outbreak is to release the biological control agents well before sirex populations approach outbreak levels. The biological control agents require a number of years after release to increase their populations and to reach an equilibrium with the sirex population. Therefore, releases should begin promptly after sirex is detected in an area because a sirex population can increase rapidly in a susceptible plantation.

Recommendations for releasing parasitoids have lacked quantitative details, which resulted in releases with little chance of establishment (e.g., too few females released) and releases of dubious benefit (e.g., repeated releases in the same compartment). Previous releases of parasitoids should be investigated to determine establishment success and rate of spread. These results will aid in making quantitative recommendations for parasitoid releases. A strategy for releasing parasitoids should optimise the probability of establishment (number of females per release site) and geographic distribution (number and distribution of release sites) using the limited number of parasitoids available for release.

Ibalia leucospoides was considered "the most effective of the parasitoids" in Victoria, based on data from insectary cultures and field establishments (Australian Forestry Council 1980, Neumann and Morey 1984, Neumann *et al.* 1987). However, a life table study is necessary to determine regulating capability for each parasitoid species (e.g., Taylor 1978). Without similar studies in the specific environmental conditions of mainland regions, statements of "parasitoid effectiveness" are inconclusive. Therefore, all five parasitoid species should be released without bias.

The original recommendation "to inoculate the nematode into the advancing front of sirex infestations" (Bedding and Akhurst 1974) must be followed. Further studies are needed to specify the number of trees to inoculate relative to the sirex population level and the optimum spatial distribution of these inoculations.

Evaluation of Biological Control Agents

Evaluations, following the release of biological control agents, are essential for implementing an efficient control program. These evaluations should determine establishment, distribution, and population levels of each biological control agent. Then informed decisions can be made on the need for additional releases.

Nematode evaluations should quantify the infection levels for inoculated and uninoculated trees from specific compartments. Evaluations may be done by dissecting sirex emerging from caged logs. Results from inoculated trees can be used to assess the success of releasing nematodes into a sirex population; while results from uninoculated trees can be used to estimate the infection level within a sirex population.

Geographic distribution of each parasitoid species should be assessed. First, locations of release sites need to be mapped for each species. Then sample logs from sirex-attacked trees near previous release sites can be caged to confirm establishment. After establishment is confirmed, further sampling in adjacent localities will indicate the extent of spread.

A Strategy for Sirex Control

Information and procedures on various components of sirex control have been researched and developed (e.g., Bedding 1967, 1972, 1974, 1979, Bedding and Akhurst 1974, CSIRO 1974, Madden 1975, Madden and Irvine 1971, Neumann 1979, Neumann and Minko 1981, Neumann *et al.* 1982, 1987, Taylor 1967, 1976, 1978, 1981). However, these components have not been integrated into a comprehensive strategy. As a guide, a sirex control program should proceed through the following sequence of actions:

- Prepare a written strategy with clear, specific, quantitative objectives.
- Review thinning status relative to the optimum and plan to minimise any delays.
- Implement a sirex detection program that will provide evidence of establishment at an early stage.
- Quantify sirex impact (number of sirex-infested trees/ha) and changes in sirex populations within sample compartments.
- Map sirex distributions using detection and monitoring data.
- Inoculate trees with *D. siricidicola* based on the sirex level and results from previous nematode evaluations.
- Release all five parasitoid species, and optimise their geographic distribution and probability of establishment.
- Confirm the establishment of the biological control agents near release sites.
- Estimate the distribution and population levels of each biological control agent.
- Collate and review all sirex data, summaries, and reports, annually.
- Review the strategy, annually.
- Plan the work schedule for the next year.

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