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Insect pest management in Australian radiata pine plantations

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Summary

Australian plantations of introduced *Pinus radiata* (ca 432,000 ha) have generally been free from significant insect damage, though many indigenous defoliators and some wood borers have adapted to pine, and several introduced bark or wood borers have become established. Among the latter only the bark beetle *Ips grandicollis* in South and Western Australia, and the wood wasp *Sirex noctilio* in Tasmania and Victoria, have caused deaths in generally unthrifty stands, particularly those droughted or variously damaged. The essential elements of the pest management strategy include: strict quarantine at ports of entry and between States; an effective diagnostic service by Commonwealth and State agencies; preventative control through tree improvement programs, stand hygiene, timely selective thinning and fire prevention; routine plantation surveillance by local foresters throughout the year, supplemented by specialist ground or aerial pest monitoring surveys, or both; physical, biological and occasional chemical curative control; research into all aspects of pest management; and finally, education through government and tertiary institutions.

Introduction

In Australia, plantations of Californian *Pinus radiata* D. Don currently extend over ca 432,000 ha, being equivalent to around one per cent of the total Australian productive forest area (Table 1). These plantations supply about 20 per cent of the annual production (or 2.9 million m^3 of round wood volume under bark) in sawlogs, veneer logs, sleepers, pulpwood and preservative-treated round wood (Forestry and Timber Bureau 1978). The Production Forestry Development Plan of the Australian Government is to increase the plantation area to over one million ha by the year 2010. The objectives of the Plan are: to alleviate a natural shortage of softwoods, to stimulate Australian wood-based industries; and to achieve self sufficiency in wood production, with exotic conifer plantations (mainly *P. radiata*) producing 65 per cent of the total estimated annual wood requirement (or 18.2 million m^3 round wood volume under bark) (Australian Forestry Council 1974).

Research into ways and means of protecting this extensive, valuable, and increasingly significant national resource from the detrimental effects of insect pests, diseases and fire, as well as from effects of nutrient deficiencies, has received high priority among Australian forest scientists in recent years. The object of this paper is to examine briefly the insect pest factor, by summarizing current pest status and evaluating present Australian practices with respect to pest management in radiata pine plantations.

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The pine ecosystem and the status of pests

Radiata pine plantations have been established within a narrow coastal belt in Western Australia and south-eastern Australia, as well as in Tasmania (Figure 1). They are generally managed over a 40-year rotation, and are grown on low-productivity eucalypt forest sites, or on reclaimed agricultural land in areas receiving around 800 mm of annual rainfall. Some plantations are occasionally affected by prolonged severe droughts, particularly on the mainland. The established plantations are ecologically simple, with individual stands evenaged and with few understorey native trees, shrubs, ferns and annuals. However, significant areas of native vegetation are retained on plantation boundaries, along permanent streams and on steep slopes. This practice has not only mitigated against erosion after site preparation, but has also provided refuge areas for native fauna. Assessments in recent years have confirmed that pine plantations support a wide range of native vertebrate animals and of insects, though not to

Table 1. Plantation areas (ha) of *Pinus radiata* in Australia

	State or territory							
	VIC	NSW	SA	TAS	WA	ACT	QLD	Total
Area of established plantations (31 March 1977)	134 788	131 568	82 912	38 828	29 072	12 121	2 487	431 776
New areas established during year 1976/77	8 896	7 192	1 662	3 073	3 655	33	79	24 590
Plantation area as a percentage of the total productive forest area	2.17	0.85	82.91	1.39	0.91	12.12	0.02	1.00

Source: Forestry and Timber Bureau (1978)
VIC = Victoria; NSW = New South Wales; SA = South Australia; TAS = Tasmania; WA = Western Australia; ACT = Australian Capital Territory; QLD = Queensland

the same extent as eucalypt forest (Gepp 1976, Suckling *et al.* 1976, McIlroy 1978, Neumann 1978).

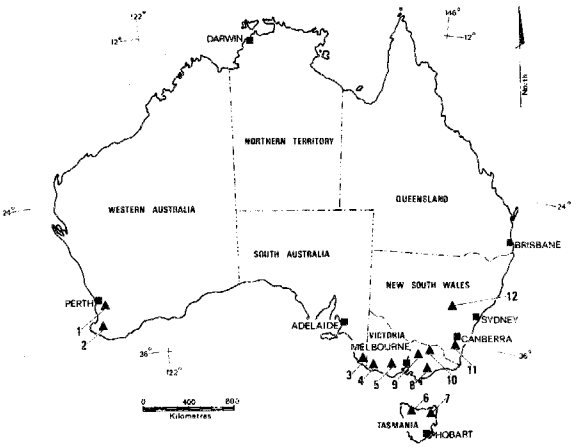

Figure 1. Location of major radiata pine forest industry centres in Australia. Numerals : 1 Perth plantations (sawn timber, particle board); 2 Manjimup plantations (sawn timber, particle board); 3 Mt. Gambier plantations (sawn timber, particle board, paper pulp); 4 Portland plantations (sawn timber, particle board); 5 Colac-Ballarat-Daylesford plantations (sawn timber, particle board); 6 Burnie plantations (sawn timber, particle board); 7 Mid-north and north-eastern plantations (sawn timber, particle board); 8 East-central highlands and West Gippsland plantations (sawn timber, paper pulp); 9 Benalla-Mansfield-Alexandra plantations (sawn timber, paper pulp); 10 Ovens Valley-Upper Murray plantations (sawn timber, paper pulp); 11 Tumut plantations (sawn timber, particle board, paper pulp); 12 Bathurst-Oberon (sawn timber, particle board, paper pulp). Source: Australian Forestry Council (1974).

On world standards, forests which are unevenaged and ecologically complex, with substantial floral and faunal diversity, appear to be less susceptible to the ravages of insect pests than those of more homogeneous structure (Graham 1963, Matthews 1976, U.S. Dept. Agric. 1977). Fortunately, the relatively simple Australian pine monocultures have generally remained free of significant insect damage. This has occurred in spite of the adaptation to pine of many indigenous defoliators, lower stem or root borers, and the establishment in plantations of several introduced borers of the bark and outer sapwood and one wood borer (Table 2). The only species to have caused damage of major economic importance are as follows: the North American bark beetle *Ips grandicollis* Eichhoff (Scolytidae); the European wood wasp *Sirex noctilio* Fabricius (Siricidae), accidentally introduced into Tasmania from New Zealand during the 1940's (Coutts 1965) and from there into Victoria during the 1950's; as well as the indigenous undescribed moth defoliators *Lichenaula* sp. and *Procometis* sp. (Xyloryctidae) and *Chlenias* spp. (Geometridae) (Table 2). In forest nurseries and young plantations, native grasshoppers (Acrididae) have been occasionally troublesome.

The pest management scheme

The pest management strategy that has evolved in Australia over the past few decades is summarized in Figure 2. The few occurrences of pest

Table 2. The more important destructive insects on radiata pine nursery stock and plantation trees in Australia

Species	Locations *	Injurious stages and type of injury	Comments	References
Acropolitis ergophora Meyrick (Lepidoptera : Tortricidae)	NSW	Larvae: damage to needles	Damage usually moderate in plantations	Moore (1972)
A. rudisana (Walker)	NSW	As above	Damage sometimes severe on nursery stock	As above
Agrotis infusa (Boisduval) (Lepidoptera : Noctuidae)	NSW, SA, VIC	Larvae: damage to bark on stems and roots, and to needles near ground level; may cause death	Attack sometimes severe causing heavy loss of nursery stock	Moore (1962), Neumann and Marks (1976)
A. munda Walker	NSW, SA	As above	As above	Moore (1962)
Austracris guttulosa (Walker) (Orthoptera : Acrididae)	SA	Nymphs and adults: damage to needles and shoots	In young plantations	Woods and Forests Department, South Australia (1974/75)
Chlenias spp. (Lepidoptera : Geometridae)	SA, TAS, VIC	Larvae: damage to soft bark and shoot tips	In young plantations defoliation can be severe, and affected trees may be predisposed to attack by *Sirex noctilio*	Minko (1961), Neumann and Marks (1976), Madden and Bashford (1977a, b)
Chortoicetes terminifera (Walker) (Orthoptera : Acrididae)	SA	Nymphs and adults: damage to needles and shoots; may cause death	Attack confined to young trees in plantations	Woods and Forests Department, South Australia (1974/75)
Clania tenuis Meyrick (Lepidoptera : Psychidae)	NSW	Larvae: damage to needles	Small trees may be completely defoliated, damage moderate on larger trees	Moore (1962)
Coccus hesperidum Linnaeus (Hemiptera : Coccidae)	NSW	Nymphs and adults: damage to needles	Attack sometimes severe and associated with sooty mould	Moore (1962)
Digglesia australasiae (Fabricius) (Lepidoptera : Lasiocampidae)	NSW	Larvae: damage to needles	Damage usually moderate in plantations	Moore (1972)
Diphucephala colaspidoides Gyllenhal (Coleoptera : Scarabaeidae)	SA	As above	Attack confined to young plantings	Woods and Forests Department, South Australia (1974/75)
Ectropis excursaria Guenée (Lepidoptera : Geometridae)	SA	Larvae: damage to growing tips and terminal buds	Widespread in some plantations	
Epiphyas caryotis (Meyrick) (Lepidoptera : Tortricidae)	NSW	Larvae: damage to needles	Damage usually moderate in plantations	Moore (1972)
E. postvittana (Walker)	NSW, SA, VIC	Larvae: damage to needles, shoots and terminal buds	Attack occurs on nursery stock and in young plantations	Moore (1962), Neumann and Marks (1976)
Euxoa radians (Guenée) (Lepidoptera : Noctuidae)	NSW	Larvae: damage to roots and lower stems	Damage sometimes severe on nursery stock	Moore (1962)
Haploceros sphenotypa	NSW	Larvae: damage to needles	Attack usually moderate in plantations	Moore (1972)

Table 2. (continued)

Species	Locations *	Injurious stages and type of injury	Comments	References
Euxoa radians (Guenée) (Lepidoptera : Noctuidae)	NSW	Larvae: damage to roots and lower stems	Damage sometimes severe on nursery stock	Moore (1962)
Haploceros sphenotypa Turner (Lepidoptera : Geometridae)	NSW	Larvae: damage to needles	Attack usually moderate in plantations	Moore (1972)
Heliothis punctigera Wallengren (Lepidoptera : Noctuidae)	NSW	As above	Damage sometimes severe on nursery stock	Moore (1962)
Heliothrips haemorrhoidalis Bouché (Thysanoptera : Thripidae)	NSW, VIC	Nymphs and adults: damage to needles, chlorosis or silvering of foliage, death of lower branches	Damage sometimes severe on natural regeneration in mature stands during summer	Minko (1961), Moore (1962)
Heteronyx obesus Burmeister (Coleoptera : Scarabaeidae)	SA	Larvae: tree death	Attack common in young plantations during drought periods	
Hyalarcta huebneri (Westwood) (Lepidoptera : Psychidae)	NSW, QLD, SA, VIC	Larvae: damage to needles	Damage usually moderate in plantations, young trees may be completely defoliated	Minko (1961), Moore (1962)
*Hylastes ater*** (Paykull) (Coleoptera : Scolytidae)	NSW, SA, VIC	Larvae and adults: damage to cambium in stems and roots and to bark of mature trees, logs and stumps	Damage sometimes severe on nursery stock and young plantings	Moore (1962), Neumann and Marks (1976)
*Hylurgus ligniperda*** (Fabricius) (Coleoptera : Scolytidae)	VIC	As above	As above	Neumann (1978)
*Ips grandicollis*** (Eichhoff) (Coleoptera : Scolytidae)	SA, WA	Larvae and adults: may kill trees by feeding on inner bark and outer sapwood; wood staining fungi always associated with attack	Important in unthrifty plantations affected by drought	Rimes (1959), Morgan (1967), Woods and Forests Department, South Australia (1974/75)
Lichenaula sp. (Lepidoptera : Xyloryctidae)	VIC	Larvae: damage to needles on terminal shoots; mortality of suppressed trees	Effects most marked after drought in plantations of intermediate age; 2-year life cycle	Neumann (1976)
Merophyas divulsana (Walker) (Lepidoptera : Tortricidae)	NSW, SA	Larvae: damage to needles and terminal buds	Damage usually moderate on nursery stock and young plantings	Moore (1972)
Merimnetes oblongus Blackburn (Coleoptera : Curculionidae)	VIC	Adults: damage to young shoots	Attack confined to young plantings	Neumann and Marks (1976)

Table 2. (continued)

Species	Locations *	Injurious stages and type of injury	Comments	References
Neomerimnetes obstructor Blackburn (Coleoptera : Curculionidae)	SA	Adults: damage to needles	Attack confined to nursery stock or young plantings in newly ploughed pastures	
Nysius vinitor Bergroth (Hemiptera : Lygaeidae)	NSW	Nymphs and adults: damage to shoots	Attack associated with 'dieback' of nursery stock	Moore (1962)
Ochrogaster contraria Walker (Lepidoptera : Notodontidae)	VIC	Larvae: damage to needles	Attack confined to young plantings on dry northerly aspects. First recorded in November 1978	
Oiketicus elongatus Saunders (Lepidoptera : Psychidae)	NSW	As above	Damage usually moderate in plantations	Moore (1962)
Orgyia anartoides Walker (Lepidoptera : Lymantriidae)	NSW, QLD SA, VIC	As above	Attack sometimes severe on small trees but only moderate on large trees; nursery stock is susceptible	Minko (1961), Moore (1962)
Panacela lewinae Lewin) (Lepidoptera : Eupterotidae)	NSW, VIC	As above	Damage severe only on small trees	Moore (1962)
Phaulacridium vittatum (Sjöstedt) (Orthoptera : Acrididae)	SA	Nymphs and adults: damage to needles and shoots; may cause death of young trees	An occasional problem in nurseries or young plantations	Woods and Forests Department, South Australia (1974/75), Neumann and Marks (1976)
*Pineus laevis*** Maskell (Hemiptera : Adelgidae)	ACT, NSW, QLD, SA, VIC, WA	Nymphs and adults: damage to needles and shoots; reduction in foliar moisture and phosphorus content	Effects most marked in drought stressed stands on marginal sites	Neumann and Marks (1976), Tanton and Alder (1977)
Procometis sp. (Lepidoptera : Xyloryctidae)	SA	Larvae: damage to needles	Effects most marked in drought stressed stands; 1-year life cycle	Woods and Forests Department, South Australia (1961/62-1967/68)
*Sirex noctilio*** Fabricius (Hymenoptera : Siricidae)	TAS, VIC	Larvae and adults: degrade to wood, and death of trees from combined effects of a phytotoxic mucus and the pathogen *Amylostereum areolatum* (Fries) Boidin.	Effects severe in unthrifty plantations of intermediate-age affected by drought	Gilbert and Miller (1952) Irvine (1962), Coutts (1969 a, b) Madden (1975, 1977)
Trigonocyttara clandestina Turner (Lepidoptera : Psychidae)	NSW	As above	Damage sometimes severe on nursery stock	Moore (1962)

* Locations where insect has been a problem. ACT = Australian Capital Territory, NSW = New South Wales, QLD = Queensland, SA = South Australia, TAS = Tasmania, VIC = Victoria, WA = Western Australia.

** Introduced species

pathogen *Amylostereum areolatum* (Fries) Boidin.				
Trigonocyttara clandestina Turner (Lepidoptera : Psychidae)	NSW	As above	Damage sometimes severe on nursery stock	Moore (1962)

* Locations where insect has been a problem. ACT = Australian Capital Territory, NSW = New South Wales, QLD = Queensland, SA = South Australia, TAS = Tasmania, VIC = Victoria, WA = Western Australia.

** Introduced species

outbreaks in the theoretically 'high risk' Australian monocultures of pine are to some extent a reflection of the success of this scheme. Because radiata pine is exotic, introduced pests of pine from Europe, North America and New Zealand (summarized in Novak 1976, U.S. Dep. Agr. 1977 and by Alma 1977) pose as its greatest threat in this country. Stringent plant quarantine is therefore considered one of the most essential elements of pest management (Lawrence 1963). Quarantine involves the careful inspection upon arrival of all imported logs and other wood products, and of seed and nursery stock by experienced staff of the Commonwealth Plant Quarantine Service. Any infested or suspect material is fumigated under strict specifications and supervision before release, and prohibited material is destroyed. As a result of this policy exotic softwood pest introductions have been kept to a minimum (Wylie and Yule 1977, Mekhamer pers. comm.). With respect to *Sirex noctilio* in Victoria, the former policy of placing infested land holdings in quarantine is being replaced by a policy aimed at containing the pest within infested areas by means of frequent inspection of softwood mills and prohibition of transport of sawn pine wood to 'Sirex-free' areas (unless milled to below 2.5 cm thickness or kiln-dried) and of all untreated round-wood. As well, preservative-treated round-wood sawn from unhealthy or recently dead trees cannot be transported outside the infested areas during the pest's pupal and emergence period between spring and autumn. The latter precaution is necessary as pupae and pharate adults may not be killed by pressure treatments of infested wood.

Other important components of pest management (Figure 2) are: preventative control; routine surveillance of plantations by district staff throughout the year (supplemented by specialist ground and aerial photographic surveys with normal colour or colour infra-red films (Incoll *et al.* 1974, Ward *et al.* 1974) of outbreaks such as those of *S. noctilio* in east-central Victoria); and research into the ecology and control of damaging species. Continuing education, largely through the dissemination of technical information, is also an essential activity of pest management.

As damage from pests to the foliage or the wood of living trees has been most marked in slow growing or fire-damaged stands, preventative control has aimed essentially at tree and stand improvement by: improvement of nursery practices to upgrade the quality of seedling planting stock (Minko and Craig 1976), and breeding trees for increased vigour and general health (Pederick 1978); the use of modern and effective fire prevention, detection and control techniques (Luke and McArthur 1978); and timely selective thinning for the early removal of deformed and low vigour trees, and for minimizing inter-tree competition. The use of district staff, instead of visiting survey specialists, for the detection of early symptoms of new pest outbreaks has reduced costs, and ensured that responsibility for detection rested with trained foresters most familiar with local conditions. Most importantly, it has shortened the time span between detection in the field and action by research entomologists in co-operation with forest protection specialists.

Curative control (Figure 2) has involved the application of silvicultural and biological techniques in older plantations and the occasional use of insecticidal sprays (organochlorine and organophosphorus compounds) as an emergency measure especially against locust swarms in both nurseries and young plantations. Examples of silvicultural control include: salvage felling associated with burning of infested bark and slash for the destruction of *Ips grandicollis* in South Australia (Morgan 1967); the felling and burning of dying or recently killed trees during winter for control of *S. noctilio* larvae in Tasmania and Victoria during the 1960's; and sanitation felling followed by burning of moth-infested crowns in unthinned stands of intermediate-age in south-central Victoria (Neumann 1976).

Biological control of *S. noctilio* (Sirex) has been attempted in both Tasmania and Victoria. Most promising among the imported, and now well established, biological control agents are: the Sirex-specific parasitoids *Ibalia leucospoides* (Hochenwarth) and *I. ensiger* Norton (Ibaliidae) which kill eggs and early larval instars; *Rhyssa persuasoria* Linnaeus, *Megarhyssa nortoni nortoni* (Cresson) (Ichneumonidae) and *Schlettererius cinctipes* (Cresson) (Stephanidae) (Taylor 1976), which are lethal to older larval instars; and the nematode *Deladenus siricidicola* Bedding (Neotylenchidae). This latter parasite sterilizes Sirex females by destroying eggs in ovaries without impairing general vigour and sexual competitiveness (Zondag 1962, 1969). Furthermore, *D. siricidicola* feeds on the

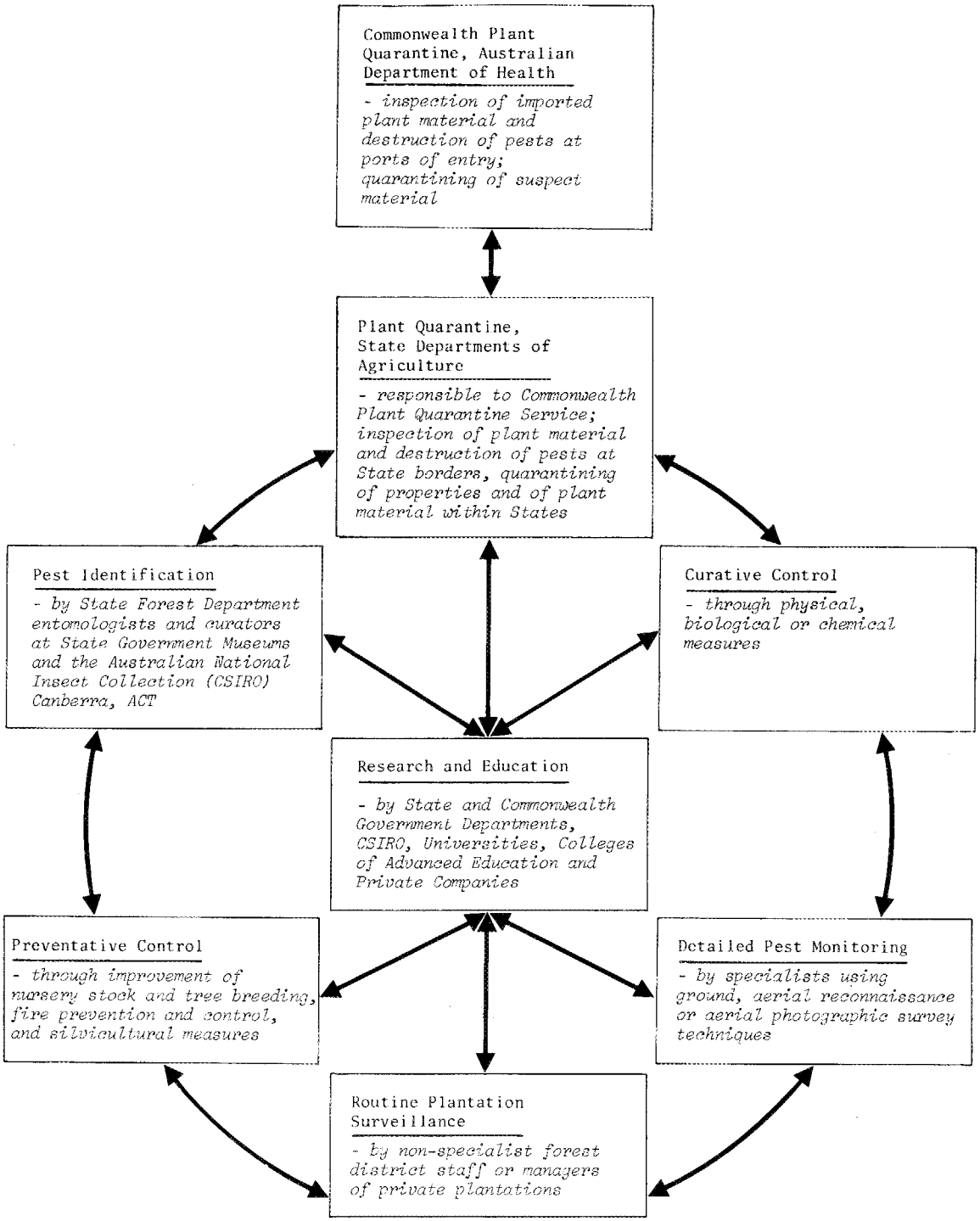

Figure 2. The basic elements of the pest management scheme in Australian radiata pine plantations.
CSIRO = Commonwealth Scientific and Industrial Research Organization.

pathogenic fungus *Amylostereum areolatum* (Fries) Boidin (Bedding 1972) which is a symbiote of Sirex and a food source for its larvae. Bedding and Akhurst (1974) and Taylor (pers. comm.) have observed in Tasmania that competition for fungal food between the nematodes and Sirex larvae may result either in early larval death from starvation or in smaller (and hence less fecund) wasps. Parasitized Sirex females oviposit normally, and introduce into trees nematode-infected non-viable eggs, phytotoxic mucus and the fungal pathogen. Trees may still die as a consequence of such attack due to the combined lethal effects of mucus and pathogen (Coutts 1969 a, b), though no larvae will develop in the wood other than those derived from healthy parental females that attacked the trees. These larvae may become parasitized by nematodes present in the trees, and the sterile female wasps that develop from these infected larvae will be capable of spreading nematodes to additional trees in the coming summer to autumn period. Nematodes are being artificially introduced into plantations by the injection of a preparation of nematodes in gelatin into the trunks of recently-felled Sirex-infested trees during winter or early spring (Bedding and Akhurst 1974).

In the generally drought-free northern Tasmanian plantations, a combination of *D. siricidicola* and insect parasitoids has been associated with the reduction of Sirex populations to very low levels within about 3 years, and the plantations were saved from serious economic damage (Taylor pers. comm.). However recent surveys near Mansfield, Victoria, have indicated that the established biological control agents alone cannot check *Sirex* in drought-stressed plantations of intermediate-age (Walls 1977) that have remained unthinned due to unfavourable markets and unavailability of funds for sanitation felling. In these plantations, steadily increasing numbers of low-vigour Sirex-susceptible trees became available. This resulted in Sirex from adjacent areas being attracted, and allowed a significant build-up of the pest population despite that more than 70 per cent of the insects were parasitized by nematodes. (McKimm pers. comm.). The ultimate result may be that an ecological balance between Sirex and biological control agents will only be established in these plantations at a very high and unacceptable level of tree mortality. As physiologically stressed trees are most susceptible to Sirex (Coutts 1965, Coutts and Dolezal 1966, Madden 1968, 1975, 1977), research in Victoria now aims at formulating a control strategy that combines the effects of biological control with those of minimal selective non-commercial thinning (a form of silvicultural control) sufficient for containing Sirex at low uneconomic levels over a wide range of climatic conditions. The feasibility of using systemic fungicides and insecticides injected into stems for the protection of final crop trees in intermediate-age plantations will also be assessed.

The outlook for the future

As the current policy by the Australian and State governments is to substantially enlarge the area of radiata pine plantations by the end of this century, increasingly heavy demands will be placed on already limited monetary and staff resources available for: surveillance of plantations; monitoring and implementation of curative controls of pests; as well as research into the ecology, population dynamics and the many aspects of management of both introduced and native destructive insects.

The Forest Services are therefore facing a formidable challenge. This might best be met if planned plantations are established with genetically improved seedlings on suitable sites, and are properly managed for sustained health and vigour. Furthermore, the current practice of retaining substantial areas of native vegetation near or within plantations is expected to result in greater diversity of the fauna and flora in the pine environment, a trend which is likely to contribute to ecological balance among destructive and other insects within plantations, and is also consistent with the aims of conservation.

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