ENTOMOPHAGA, 21 (4), 1976, 429-440

THE INTRODUCTION AND ESTABLISHMENT OF INSECT PARASITOIDS TO CONTROL *SIREX NOCTILIO* IN AUSTRALIA

K.L. TAYLOR

Division of Entomology, CSIRO, Stowell Avenue, Hobart, Tasmania.

To control the woodwasp *Sirex noctilio* F., accidentally introduced into Australia some time prior to 1952, natural enemies were collected in many parts of the northern hemisphere between 1962 and 1973. A total of 21 species of insect parasitoids were introduced to Tasmania for culturing, and 10 of these, with subspecies and geographic races, have been released in Tasmania and Victoria. Five species are now established.

Ibalia leucospoides HOCHENW. (subspecies *leucospoides* and *ensiger* NORTON) and *Megarhyssa nortoni* (CRESSON) (subspecies *nortoni* and *quebecensis* (PROVANCHER)) were the most rapid colonizers, *M. nortoni* having colonized one area following the liberation of only 10 females. *Rhyssa persuasoria* (L.) appears to be adaptable although slow to colonize. *Ibalia rufipes drewseni* BORRIES attacks host larvae hatching from overwintering eggs. *Schlettererius cinctipes* (CRESSON) emerges later in the season than *M. nortoni* and *R. persuasoria* and so far its abundance has remained low when one or both of these species are present. Of the species not yet established, *Rhyssa hoferi* ROHWER from the arid zone of the U.S.A. is the most promising.

Early indications from evaluation studies are that a combination of the insect parasitoids, and parasitic nematodes which have also been introduced, will achieve a high level of biological control.

The great shortage of softwoods in the natural forests of Australia has led to a long standing policy, in all States, of planting exotic conifers. Commercial plantations consisting mainly of *Pinus radiata* D. DON. now exceed half a million hectares and return approximately $ 250 million per annum.

Even before the woodwasp *Sirex noctilio* F. was discovered in southern Tasmania in 1952 it was recognized as a serious threat to the valuable pine plantations in Australia, since this species had caused considerable damage to *P. radiata* plantations in New Zealand. By 1961, *S. noctilio* had killed some 40% of the standing trees in a private plantation at Pittwater, near Hobart.

Following the discovery in 1961 that *Sirex noctilio* was established in Victoria and the setting up of the National Sirex Fund, a world-wide search for natural enemies of siricids was instituted (TAYLOR, 1967a). At that time the plantation at Pittwater contained the only known high population of *S. noctilio* in Australia. The Division of Entomology, CSIRO, therefore established a research station at Hobart airport, where parasitoids could be received, reared, and distributed to Sirex-infested areas in Tasmania and Victoria. This station was also equipped for studies on the ecology of *S. noctilio* and the parasitoids.

The search for parasitoids in the northern hemisphere was completed in 1972 and the last consignments of insects emerging from material collected in south-eastern U.S.A. were received at Hobart in 1973. This paper is a record of the project up to the end of 1975. It covers only insect parasitoids: parasitic nematodes have also been introduced which show great potential as biological control agents.

COLLECTION AND IMPORTATION OF PARASITOIDS

Natural enemies in the European zone were collected by staff of the Division of Entomology. The Sirex Biological Control Unit was established at Silwood Park in the U.K. for this purpose, and to study the ecology of siricids and their natural enemies in Europe. Siricid-infested material from most European countries, Turkey and North Africa was shipped to Silwood Park, and parasitoids emerging from it were consigned by air to the Tasmanian laboratory. Until 1971, all collections in other parts of the world were made by the Commonwealth Institute of Biological Control, except for one small consignment despatched from Vancouver by Dr. B.P. Beirne. The CIBC consigned parasitoids from India, Pakistan, the U.S.A. (California and Nevada), and Canada (New Brunswick). An officer of the CIBC also carried out an initial search in Japan in 1962, and small numbers of *Megarhyssa praecellens* (Tosquinet) (*Hym. Ichneumonidae*) were sent to New Zealand that year, because at that stage the Hobart insectary was not ready to receive parasitoids. When the station at Silwood Park was closed in 1971, one officer was transferred to Japan to search more extensively and one to the U.S.A. to search for material in the arid zone. The latter returned to south-eastern U.S.A. for a short period in 1972 to collect there. In all of these countries, both the CIBC and CSIRO officers received very considerable assistance from local institutions.

The methods of collection and shipping have been described in a previous paper (Taylor, 1967a). Most of the insects received since 1967 have emerged from logs collected in the field and held in insectaries.

General Biology of Siricids and Parasitoids

In Tasmania *S. noctilio* emerges from infested trees between mid-January and the end of April; this period varies a little with seasonal conditions. Within a few days after emergence the females drill into selected trees to inject the symbiotic fungus *Amylosterium areolatum* Gaut and lay their eggs. The fungus must begin to grow in the wood before the eggs will hatch (Madden, 1968). In most trees this occurs within 3-5 weeks, but in some the development of the fungus is delayed because the water content of the wood remains high, and hatching of the eggs may be delayed for as long as 12 months (Spradbery, 1974, and unpublished information). The newly hatched larvae bore through the fungus-affected wood, moving deeper into the wood as they grow. Their ultimate size and the duration of the larval stage depends upon water content and the supply of nutrients in the wood. Most larvae turn back towards the bark before pupating. Emergence of each generation may take place over a period of 3 years after the eggs are laid.

The 1st group of parasitoids to attack the siricids are the ibaliids. All of these attack the 1st or 2nd instar larvae just before or soon after eclosion. They are attracted to the oviposition drills of the host only when the fungus begins to grow, and this coincides with the hatching of the egg (Madden, 1968; Spradbery, 1974). The parasitoid egg is laid within the host larva. The 1st 3 instars are endoparasitic (Chrystal, 1930) but the 3rd instar emerges from the host larva and feeds externally. *Ibalia leucospoides* Hochenw. [*Hym.* : *Ibaliidae*], its subspecies and *I. ruficollis* Cameron emerge in summer and autumn to attack siricid larvae hatching soon after oviposition. *I. rufipes rufipes*

CRESSON, *I.r. drewseni* BORRIES and *I. aprilina* KERRICH emerge in spring to attack siricid larvae in trees where the hatching of the eggs has been delayed (SPRADBERY, 1970a; KERRICH, 1973).

All other parasitoids attack later in the development of the siricids and possess a long ovipositor which is inserted through the wood to reach the host larvae. Host finding in *Rhyssa persuasoria* (L.) (*Hym.: Ichneumonidae*) (SPRADBERY, 1970b) and *Megarhyssa nortoni* (CRESSON) (*Hym.:Ichneumonidae*) (MADDEN, 1968) depends upon renewed growth of the symbiotic fungus and of other micro-organisms in the moist area immediately behind the feeding siricid larva. The mechanism is probably the same for other species. The host larva is paralysed by stinging and the parasitoid egg is laid on the body surface. The parasitoid larva feeds externally and after consuming the host pupates in the same cell in the wood (HOCKING, 1968). In this group of species, most members of each generation enter diapause in the larval stage when fully fed and pupate the following spring to emerge at a time when the host larvae are boring back towards the bark to pupate. Those which do not enter diapause pupate almost immediately, to emerge in early summer.

SPECIES AND STRAINS INTRODUCED

The basic strategy of the collecting in the northern hemisphere was to obtain all available species parasitizing the siricids in conifers, and strains of them from a wide range of bioclimates. Special attention was paid to mediterranean-type climatic areas because the major plantations of *Pinus* spp. (principally *P. radiata*) in Australia occur in homoclimes of those (KIRK, 1974a). The complete results of the search for, and introduction of parasitoids are given in table 1.

TABLE 1

Siricid parasitoids imported to Tasmania 1962-1973

SPECIES	ORIGIN AND NUMBERS OF FEMALES
Ibalia aprilina	Japan 54
I. leucospoides ensiger	S-W U.S.A. 68, E. Canada 2, S-E U.S.A. 51
I. leucospoides leucospoides	Europe and Turkey 1469, Morocco 40, Japan (= *suprunenkoi*) 243
I. montana	S-W U.S.A. 66
I. ruficollis	Arizona, New Mexico 97
I. rufipes drewseni	Europe 161, Turkey 4
I. rufipes rufipes	Eastern Canada 3, S-W U.S.A. 89
Megarhyssa emarginatoria	Europe 55
M. nortoni nortoni	California, Nevada 291, Brit. Columbia 8, Arizona (includes *quebecensis*) 67
M.n. quebecensis	Eastern Canada 9, Arizona (see *nortoni*)
M. praecellens	Japan 132
Megischus sp.	S-E U.S.A. 2
Pristaulacus ater	S-E U.S.A. 5
Odontocolon geniculatus	Europe 71
Rhyssa alaskensis	S-W U.S.A. 49
R. amoena	Europe 12
R. crevieri	Eastern Canada 31
R. hoferi	Arizona, New Mexico 34
R. howdenorum	S-E U.S.A. 95
R. jozana	Japan 26
R. lineolata	New Zealand 30, E. Canada 21, S-E U.S.A. 9
R. persuasoria himalayensis	India 352 (+ 193 larvae)
R.p. persuasoria	Europe, Turkey 930, Calif., Nevada 22, E Canada 70, Morocco 23, Arizona, New Mexico 155, Japan 65, S-E U.S.A. 5
Schlettererius cinctipes	California, Nevada 95, Arizona, New Mexico 122

Four of the species consigned to Tasmania were not previously recorded as parasitoids of siricids. *Schletterérius cinctipes* (CRESSON) [*Hym. : Stephanidae*] was assumed to be parasitic on Coleoptera like other stephanids (TAYLOR, 1967b). Culturing of this species at Hobart has proved conclusively that it is a primary parasitoid of siricids and, as it was one of the dominant species emerging from siricid-infested logs collected in 1971 in Arizona and New Mexico (KIRK, 1975), it may be important in arid climates. *Odontocolon geniculatus* KRIECHBAUMER (*Hym.: Ichneumonidae*) has also been successfully cultured on *S. noctilio* at Hobart although it is also known to parasitize Coleoptera (SPRADBERY, personal communication). Although *Megischus* sp. (*Hym.: Stephanidae*) and *Pristaulacus ater* (WESTWOOD) (*Hym.: Aulacidae*) emerged from siricid-infested logs collected in south-eastern U.S.A., they are not necessarily parasitic on siricids. No progeny of these 2 species emerged at Hobart.

KERRICH (1973) has recently revised the species of the genus *Ibalia* attacking siricids in conifers; he regards *I. ensiger* NORTON as a subspecies of *I. leucospoides* HOCHENW., *I. suprunenkoi* JACOBSON as a synomym of *I. leucospoides*, and *I. drewseni* BORRIES as a subspecies of *I. rufipes* CRESSON. He described *I. aprilina* in the same paper. Strains of *I. leucospoides leucospoides* HOCHENW. were obtained from a very wide range of localities throughout Eurasia and North Africa, and strains of *I. leucospoides ensiger* NORTON from Eastern Canada and the south west and south east of the U.S.A.

I doubt the validity of *Megarhyssa nortoni quebecensis* (PROVANCHER) as a subspecies and have not separated it in cultures from *M.n. nortoni* (CRESSON) since 1971. The consignments from Arizona in 1971 and 1972 included colour variants typical of each subspecies, with intermediate forms.

Rhyssa persuasoria persuasoria was collected over a wider range in the Northern Hemisphere than any other species. Consignments were received from most European countries, Morocco, Turkey, Canada, Western and Eastern U.S.A., and Japan. These all appear to be conspecific although differences in colour and maculation are apparent (SPRADBERY & RATKOWSKY, 1974) and minor differences in behaviour have been observed in the insectary. Differences were most noticeable in the Moroccan strain.

Two species of *Rhyssa* were collected in the Southern United States in the final stages of the search programme. *R. hoferi* ROHWER was particularly sought because it was known to occur in the arid zone of the United States and was therefore likely to be well adapted to the climate of South Australia and Western Victoria where the risk of damage by *S. noctilio* in the extensive plantations of *P. radiata* is regarded as high. *R. howdenorum* TOWNES was collected in Georgia, North and South Carolina, Alabama and Florida, from various species of *Pinus*.

CULTURING AND ACCLIMATIZATION

The methods used at Hobart for culturing the various parasitoid species have already been described (TAYLOR, 1967a). These remain basically the same, but some changes and improvements have been made in view of increased knowledge of the biology of *S. noctilio* and the parasitoids.

As the most important conifer species planted in Australia is *P. radiata*, which grows naturally in a limited area in California, and *S. noctilio* is a European species which attains its greatest density in the Mediterranean zone, we expected that some of the parasitoid species imported would fail. In addition to collecting, CSIRO officers stationed at Silwood Park carried out research on the ecology and biology of the parasitoids and their host siricids in the donor countries, including an analysis of their range in host trees, altitude and other factors (SPRADBERY & KIRK, in prep. ; KIRK 1974a, 1974b, 1975). Their work shows that certain species are specific to host trees of genera other than *Pinus* and/or to other host siricids. Good examples of this are *Megarhyssa* *emarginatoria* Thunberg and *Rhyssa amoena* Grav. which, although they oviposited on logs infested by *S. noctilio* in the insectaries at Hobart, failed in culture because the numbers emerging in the 1st generation were very low and there was no 2nd generation. Cultures of *Ibalia montana* Cresson, *R. crevieri* (Provancher), and *R. jozana* Matsumura also failed in the same way.

Additional causes have led to the failure of other species; thus *R. alaskensis* Ashmead, *R. lineolata* (Kirby), and *R. persuasoria himalayensis* Wilk. were all reared successfully in the insectary for several generations, but the proportion of females to males was usually very low and the number of females decreased with each generation.

There are many possible reasons for this unsatisfactory sex ratio (see Flanders, 1965). Alterations were made in the rearing technique to provide for the following possibilities:

1. Deficient mating (i.e. females mating with immature males);
2. Preferential oviposition (small host larvae favouring male progeny) (Clausen, 1939);
3. Differential mortality by malnutrition of larval females on small hosts;
4. Excess mating;
5. High host density leading to depletion of sperm in spermathecal glands;
6. Interference caused by crowding in culture cubicles. (Wylie, 1966; Spradbery, 1970b).

Throughout this work, the logs offered to the parasitoids were selected to provide the largest host larvae available. However, in some years the supply of field collected material was very limited, and artificial culturing of *S. noctilio* (by exposing logs to the woodwasp in the insectary or in the field) was unsatisfactory because the larvae obtained rarely reached optimum size.

Alterations made were :

a) In the cubicles where the parasitoids were emerging males were collected daily and older males introduced to replace them;

b) In the cubicles where females were ovipositing, the density of females was reduced to avoid crowding, and the number of males was maintained at an even lower level.

The yield of females from the culture of the Moroccan strain of *R. persuasoria* in 1973-1974, perhaps as a result of these changes, was much higher than in previous years. However, there was no improvement in the yield of *R. lineolata* or *R. alaskensis.*

For the 1st few years, host material for imports of *I. rufipes drewseni* and *I.r. rufipes* was prepared artificially by forcing out *S. noctilio* in warm rooms during May and June, and exposing partly dried logs to the females. These were offered to the parasitoids 3-4 weeks later. Early imports of both subspecies failed, but early in March 1968 a small consignment of *I.r. drewseni* was received at Hobart, the insects having emerged from logs kept in a warm room at Silwood Park. From these a vigorous culture was obtained and has been maintained since.

Two modified methods have been used since 1969 to culture the spring emerging species of *Ibalia*. Logs exposed to *S. noctilio* in late autumn and early winter have been stored in a cool shady place during the winter. Under these conditions some of the eggs do not hatch until late spring, thus providing the kind of host material sought by *I. rufipes drewseni* in nature (Spradbery, 1974). In addition logs containing unhatched host eggs were collected during spring from some infested trees in the field.

In 1972 further stocks of *I. rufipes rufipes* were received from Arizona, and *I. aprilina* (then undescribed) from Japan. Progeny of both emerged in the spring of 1973 but only *I. aprilina* emerged the following spring. Only 1 female of the latter emerged in 1975, so cultures of both species have now been lost.

Megarhyssa nortoni nortoni and *M.n. quebecensis* were the easiest of all species to culture and to establish in the field. Our only problem was to obtain enough logs with large host larvae.

Odontocolon geniculatus was cultured in small cages within the breeding cubicles. This species is smaller than the rhyssines, it moves much more quickly and its behaviour makes it difficult to find and to confine in cages. In 1971 culturing of *O. geniculatus* was discontinued after it had been released at two sites. However, because of its short ovipositor only a small proportion of the siricid population would be available to it, so it was unlikely to be very effective.

There is no satisfactory explanation for the failure in culture of the Japanese *Megarhyssa praecellens*. Both sexes were very shortlived in the insectary. Most of them died within a few days of emergence and there was therefore insufficient time to discover the reason. SPRADBERY (personal communication), who collected material in Japan, reported that from observations in the field and from emergence in the insectary this species was bi-voltine or probably tri-voltine. This was confirmed by emergence of the 1st 2 generations in Hobart. After the 1st season, large numbers were expected to emerge the following spring; this did not happen, and the few that emerged were dying so soon after emergence that the last 8 were liberated at Beulah in 1972 in the hope that they might reproduce in the field. Nothing more emerged from the culture later in the season.

LIBERATIONS IN TASMANIA

Generally, the liberation of the parasitoids in Tasmania (table 2) was planned so that there would be opportunities to study their ability to disperse naturally (see fig. 1), to obtain information on the conditions most suitable for each, and also to examine interspecific interactions.

The original intention was that all parasitoids should be established in the forest at Pittwater, to provide a "bank" for later distribution. However, in the past 5 years, although it has been possible to obtain large numbers of *I. leucospoides*, *M. nortoni* and *R. persuasoria* from this forest, only very small numbers of *I. rufipes drewseni* and *S. cinctipes* could be collected there.

Since 1970, every species available has been liberated in Mt. Helen State Forest, near Scottsdale in northern Tasmania. There the density of *S. noctilio* from 1971 to 1973 was higher than at Pittwater, so that the group of forests around Scottsdale seemed suitable for a second "bank". The rainfall at Scottsdale is higher than at Pittwater and the hatching of a greater proportion of *S. noctilio* eggs is delayed until spring. These conditions should favour some species which are less successful at Pittwater, for example *I. rufipes drewseni* and *S. cinctipes*. So far the relative densities of these two species are slightly higher at Scottsdale than at Pittwater.

The group of plantations around Scottsdale also provided ideal conditions for monitoring the natural dispersal of the various species, and all were liberated at the same site. However, in 1974 the number of trees killed near that site was so low that further liberations of *I. rufipes drewseni* and *S. cinctipes* were made at West Scottsdale, because of the risk that their populations in Mt. Helen S.F. might not survive.

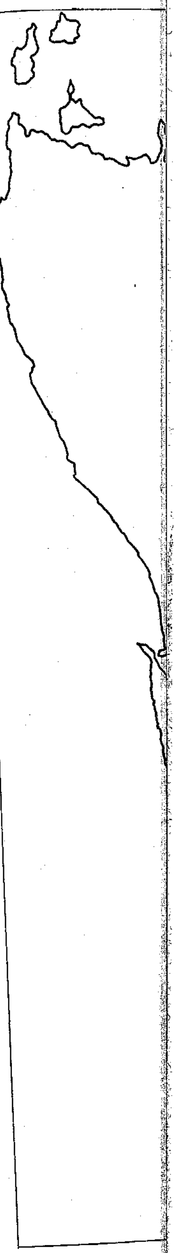

FIG. 1. Map

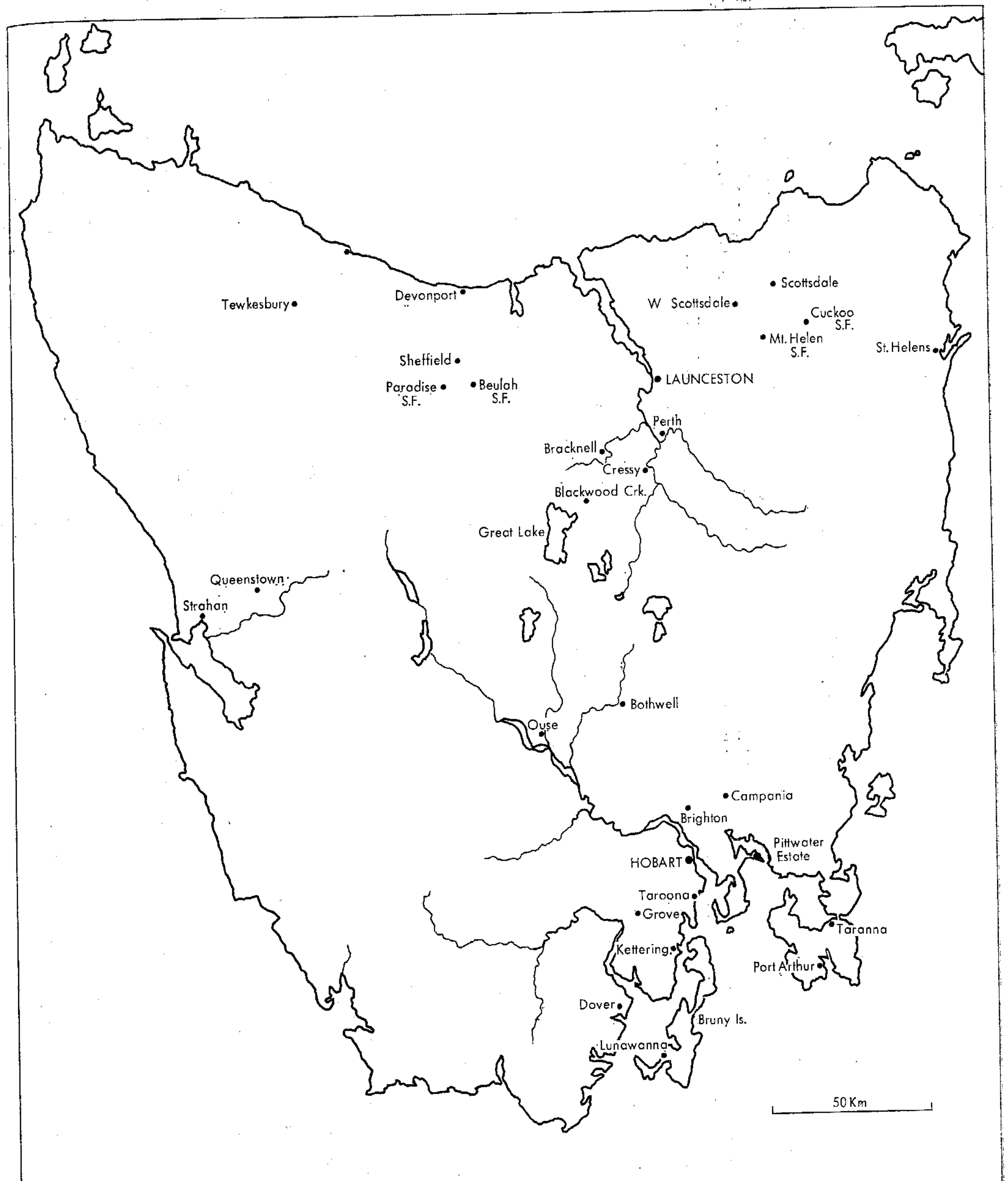

FIG. 1. Map of Tasmania showing position of localities listed in table 2.

In 1971 a high population of *S. noctilio* was discovered in the small plantation (73 ha.) at Beulah in North Western Tasmania. Five species, *I. rufipes drewseni*, *S. cinctipes*, *O. geniculatus*, *M. praecellens* and, later, the Japanese strain of *R. persuasoria*, were liberated there rather than at Pittwater or Scottsdale where their chances of establishment might have been reduced by competition from *M. nortoni* and *R. persuasoria*.

TABLE 2

Principal liberations of siricid parasitoids in Tasmania 1962-1973 (mated females)
(for other liberations see text)

	IBALIA leucospoides			*IBALIA rufipes*		*MEGARHYSSA nortoni*		*MEGARHYSSA praecellens*	*RHYSSA persuasoria*					*ODONTOCOLON*		*SCHLETTERERIUS*
	ens.	*leuc.*	*supr.*	*drews.*	*rufip.*	*nort.*	*queb.*		Eur.	N. Am.	Moroc.	Japan	*himal.*	*lineolata*	*geniculatus*	*cinctipes*
BEULAH S.F.		313*		179*		10*		8				82*			46	204*
BLACKWOOD CREEK	70*	—*				40*			20							
BRACKNELL	1172*	3100*				283*			155*							
CAMPANIA		—*				24*										
CRESSY		965*				30b										30b
MT. HELEN S.F.	561*	960*		200*		205*	50a		209*	70a				49		198*
PARADISE S.F.				22d	8d					14d	7d	31d				20d
PITTWATER	980*	619* (Medit.)	70a	50*		188*	55a		9b				92	53c	130	100*
QUEENSTOWN		120b				40d										
TEWKESBURY	53b	759b				150b	25b			133b						
WEST SCOTTSDALE				26d						10d	25d	29d				65d

* Established a Cannot be distinguished from established populatio b No samples available to determine establishment
c Recovered for next two years only d Very recent liberation

The liberations at Bracknell, Campania and Cressy were all experimental. *I. leucospoides* (both subspecies, *leucospoides* and *ensiger*), *M. nortoni* and *R. persuasoria* were liberated in large numbers for 3 years in the small plantation (0.8 ha.) at Bracknell to compare the results with those obtained by less intensive liberations elsewhere. In the small woodlot at Campania (1.4 ha.) only 24 *M. nortoni* females were liberated in 1968 to simulate a situation in which a few females might by natural dispersal reach a new siricid infested area. At Cressy, *P. radiata* is grown only in windbreaks and small woodlots to provide shelter for stock. *M. nortoni* and *S. cinctipes* were liberated there but have not yet been recovered.

The results at Bracknell showed that massive liberations *per se* did not rapidly achieve a high level of parasitization. Conversely, at Campania *M. nortoni* reached a very high relative density in 1971, only 3 years after small numbers were released. This also happened at Blackwood Creek (0.6 ha.), where 40 female *M. nortoni* were released in 1965.

The liberation of 10 females of *M. nortoni* at Beulah was also experimental, to see whether establishment would result from such a small liberation. This species emerged from several trees sampled there in 1975.

I. leucospoides and its subspecies have been liberated at a small number of widely separated sites because it is known (TAYLOR, 1967a) that this species will disperse over long distances naturally. However, new strains of this species have been liberated since 1969 at the same or at new sites; for example, the liberation of Mediterranean strains of *I.l. leucospoides* at Pittwater (see table 2). This also applies to *R. persuasoria.*

The liberations of *I. leucospoides*, *M. nortoni* and *R. persuasoria* at Tewkesbury are only recent. The density of *S. noctilio* in the private plantations there is still very low but liberations were made with the object of getting the parasitoids established as soon as possible. This also applies to the liberations in 1974-1975 of *I. rufipes drewseni*, *R. persuasoria* and *S. cinctipes* at Paradise S.F., a few kilometres from Beulah S.F.

Liberations not shown in table 1 are: *M. nortoni* at Bothwell, Sth. Bruny Is., and Kettering; *R. persuasoria himalayensis* at Grove; and *I. leucospoides* at St. Helens and Strahan.

CONSIGNMENTS TO VICTORIA AND NEW ZEALAND

In 1963 it was decided that the Forests Commission, Victoria, would maintain cultures in its own insectaries at Melbourne of all parasitoid species as they become available. Therefore as soon as cultures were established in Hobart consignments were sent to Victoria so that cultures could be set up there. Subsequently parasitoids surplus to requirements in Tasmania were consigned each year to Melbourne to supplement the Commission's own stocks for liberation (see table 3). This procedure has been varied for two species: — *I. rufipes drewseni*, which requires winter culturing of siricids for rearing, is being cultured only in Hobart and consignments are being sent to Victoria for liberation; and small consignments of *R. hoferi* were sent from Hobart in 1972 and 1973 for direct liberation in low rainfall areas in Victoria in the hope of establishing it one year earlier than would be possible under the normal procedure.

Two species liberated in Tasmania (*M. praecellens* and *O. geniculatus*) have not been sent to Victoria for reasons already discussed.

From 1966 to 1968 *Ibalia leucospoides ensiger* (412 males, 400 females) was consigned to the New Zealand Forest Research Institute, Rotorua, so that a culture of this subspecies could be established there. In 1968, when the 1st generation of the Canadian *R. crevieri* was emerging in autumn at Hobart, suitable host material was unavailable, so 25 males and 31 females were sent to Rotorua, where logs containing large siricid larvae were available.

TABLE 3

Siricid parasitoids consigned to Victoria 1962-1975

Species	Origin of strains	Mated females	Remarks
I. leucospoides ensiger	California and Canada	3 760	
I. leucospoides leucospoides	Europe (mostly Mediterranean), Japan	7 814	
I. leucospoides	mixed *ens.* and *leuc.*	18 900	
I. rufipes drewseni	Europe	387	For liberation
M. nortoni nortoni	California	1 410	
M. nortoni quebecensis	Canada	100	For culture
M. nortoni	mixed *n.* and *q.*	1 490	
R. alaskensis	California	20	For culture
R. hoferi	Arizona	96	For liberation
R. lineolata	Canada	50	For culture
R. persuasoria himalayensis	India	11	For culture
R. persuasoria persuasoria	N.Z. (= U.K.), Europe, Canada, N. America Morocco, Japan	1 547	
S. cinctipes	S-W U.S.A.	900	

DISCUSSION

It must be assumed that *S. noctilio* will become established eventually in all Australian plantations of *P. radiata* except perhaps in Western Australia where it should be possible to exclude it by strict quarantine measures. The range of climatic conditions in which *P. radiata* is grown is quite wide (KIRK, 1974a), so it is important that the complex of parasitoids established should include the widest possible range of species and geographic strains of them.

In Europe it has been found that *I. leucospoides* is the dominant parasitoid in dry areas, e.g. in the typical Mediterranean climate, whereas *R. persuasoria* tends to increase in relative abundance in Northern Europe (SPRADBERY & KIRK, in prep.). Present evidence indicates that although their relative density will vary according to the climatic conditions, both should survive in all areas where *S. noctilio* occurs in Australia.

The 5 species established at Pittwater are also established at Scottsdale where the site quality is much higher and the mean annual rainfall more than double. Early results from our field evaluation work indicate that all 5 will survive at both sites even though the numbers of 2 or 3 species (not necessarily the same ones at each site) may remain at a low level when the ecosystems reach equilibrium. There is considerable variation between trees and in any one season each species should find favourable conditions, to greater or lesser degree. Results at Pittwater also show that seasonal conditions have an important bearing on the proportion of each generation of *S. noctilio* available to any one species. If they are such that they facilitate rapid colonization of the symbiotic fungus, *I. leucospoides* will be favoured and also there will be more large larvae available for *Rhyssa* and *Megarhyssa* in the following spring. If colonization of the fungus is delayed, the density of *I. rufipes* should increase, and delayed development of host larvae should favour *S. cinctipes* which emerges later than the rhyssines.

With all species of *Rhyssa* the sex ratio (male: female) tended to be high in cultures. Even in strains of *R. persuasoria* which have been successfully cultured the numbers of females in each generation were never much greater than the numbers of parent females. This species also increased more slowly in the field than *M. nortoni*. At nearly every site where these 2 species were liberated, *M. nortoni* has increased rapidly, even where only small numbers of females were liberated. Therefore one liberation of *M. nortoni* should suffice, but 2 or 3 liberations of *R. persuasoria* in successive years are desirable.

The rapid establishment of *M. nortoni* at all study areas in Tasmania suggests that it will adapt to all climatic conditions where *S. noctilio* is likely to become established. Data from Pittwater and Scottsdale (unpublished) indicate that about 20% of each generation of *M. nortoni* is non-diapausing, and that this plays an important role in its rapid establishment. The non-diapausing component in *R. persuasoria* is smaller.

The dispersal of *M. nortoni* is also more rapid than that of *R. persuasoria*. It has been recorded at distances up to 19 km from the nearest liberation point, separated by barriers of native forest, farmlands or water. The greatest distance so far recorded for *R. persuasoria* is 7.2 km, with no major barriers.

The numbers of *M. nortoni*, *R. persuasoria* and *S. cinctipes* received from the U.S.A. (see table 1) suggest that the latter two species increase in relative density at the expense of *M. nortoni* as one moves from the west coast to Arizona, with *R. hoferi* also becoming a significant member of the complex. The trend might simply be a reflection of the conditions in the collecting areas (for example, *M. nortoni* was collected from a large burnt area in 1964), but if it is significant one might expect *S. cinctipes*, *R. persuasoria* and *R. hoferi* to play a greater role than *M. nortoni* in Western Victoria and in South Australia. The numbers of *R. hoferi* liberated so far in Victoria have been only small and further liberations in the same areas are planned.

A native ichneumonid, *Certonotus tasmaniensis* TURN. has been reared from *P. radiata* logs collected from many localities in Tasmania and Victoria. Weevils, principally *Orthorrhinus cylindrirostris* F. and *Poropterus* spp., have almost invariably emerged from the same logs so they are apparently amongst the natural hosts of *C. tasmaniensis*. HOCKING (1967) showed that this parasitoid also attacked *S. noctilio*, and data from Scottsdale (unpublished) show that it reached a level of more than 15% parasitization in 1973.

If, like other stephanids, *S. cinctipes* will also attack Coleoptera, it is possible that this species could become established in *P. radiata* forests ahead of *S. noctilio*, and thus, with *C. tasmaniensis*, play a useful role in controlling an incipient outbreak.

Early results from evaluation studies still in progress indicate that parasitization by the complex of insect parasitoids at the main study areas should fluctuate about a level of 70 % of higher. A combination of the insect parasitoids, parasitic nematodes and sound forest management should hold the population of *S. noctilio* down to a level at which economic losses will not be serious.

ACKNOWLEDGMENTS

This project was supported by the National Sirex Fund, Australia. It is not possible to list all of those who helped, both in Australia and overseas, but I gratefully acknowledge their assistance. In addition to those previously acknowledged (TAYLOR, 1967 a), I must mention in particular Mr. J. Moss and Mr. R. BASHFORD (Hobart); Dr. D.C. LLOYD (CIBC) who collected in Canada and Nevada; Dr. J.P. SPRADBERY, who collected in Japan with the help of Tokyo University; and Mr. A.A. KIRK who collected in North America with the help of Northern Arizona University, Flagstaff, and the Forestry Sciences Laboratory (U.S.D.A.), Athens, Georgia.

RÉSUMÉ

Introduction et établissement d'insectes parasitoides pour lutter contre *Sirex noctilio* en Australie

Pour lutter contre la guêpe, *Sirex noctilio* F. introduite par hasard en Australie peu de temps avant 1952, on a récolté des ennemis naturels de beaucoup de régions de l'hémisphère nord entre 1962 et 1973. On a introduit pour multiplication un total de 21 espèces d'insectes parasites; 10 de celles-ci avec leurs sous-espèces ont été libérées en Tasmanie et en Victoria. Cinq espèces sont maintenant établies.

Ibalia leucospoides HOCHENW (sous-espèces *leucospoides* et *ensiger* NORTON) et *Megarhyssa nortoni* (CRESSON) (sous-espèces *nortoni* et *quebecensis* (PROVANCHER) ont colonisé le plus rapidement. *M. nortoni* a colonisé une région après la libération de 10 femelles seulement. *Rhyssa persuasoria* (L.) paraît être adaptable mais lent à coloniser. *Ibalia rufipes drewseni* BORRIES attaque les larves-hôtes quand elles sortent des œufs d'hiver. *Schlettererius cinctipes* (CRESSON) émerge en saison plus tard que *M. nortoni* et *R. persuasoria* et jusqu'ici elle n'est pas abondante quand l'une ou les deux espèces sont présentes. *Rhyssa hoferi* ROHWER, de la zone aride des États-Unis, est l'espèce la plus prometteuse parmi celles qui ne se sont pas encore établies.

Les premières données d'études prospectives montrent qu'une association des insectes parasites et des nématodes parasites, qui ont été aussi introduits, réalisera un haut niveau de lutte biologique.

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