The Biology, Ecology and Integrated Pest Management of *Ctenarytaina thysanura* (Ferris & Klyver) (Homoptera:Psyllidae) on *Boronia megastigma* (Nees) in Tasmania

by

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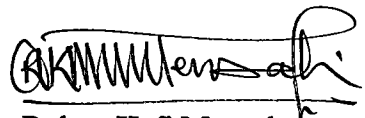
DECLARATION

This thesis contains no material which has been accepted for the award of any other degree or diploma in any University, and to the best of my knowledge contains no copy or paraphrase of material previously published by any other person except where due reference has been made.



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Summary

This study investigates the behaviour, population dynamics and integrated pest management of *Ctenarytaina thysanura* (Ferris and Klyver), a psyllid attacking *Boronia megastigma* (Nees), an essential oil crop in Tasmania, during the period 1986-1989.

C. thysanura was studied extensively on boronia plants under glasshouse and field conditions and its life cycle and biology documented.

Aspects of mating behaviour, ovipositional patterns on the host plant and the spatial distribution of *C. thysanura* eggs in relation to the position of the nodes of the host plant's terminal shoots are described. Field tests on attraction of adults to coloured sticky traps revealed a clear preference for yellow and least preference for white. Psyllid capture rates were directly related to the proportion of light reflected in the 440-480nm range.

C. thysanura was identified as a major pest of boronia causing 41.7 per cent flower yield loss in commercial stands. It confined its attack to young, actively growing boronia shoots. Feeding damage to the host plant was cumulative and very much apparent as nymphs entered the 4th and 5th stages. Based on boronia oil market values and psyllid control costs for 1988 and 1989, the economic injury level for young and mature plants was eight and 20 *C. thysanura* 4th and 5th nymphs per terminal shoot respectively.

The host-plant relationships of *C. thysanura* were studied in detail for 23 boronia cultivars. No antibiosis effect was detected for any cultivar but an ovipositional antixenosis was detected in cultivar HC27, whereas cultivars HC4 and HC142 were most preferred for oviposition. No cultivar was tolerant to *C. thysanura* attack. Measurement of terminal shoot hardness of the cultivars showed variations in relative hardness. *C. thysanura* laid more eggs on those cultivars with softer terminal shoots (HC4 and HC142) and laid few eggs on harder terminal shoots (HC27).

Detailed studies were made of the population dynamics of *C. thysanura* on boronia during 1986-1989 on 0.5 ha plots at five locations. *C. thysanura* completed

three generations each year in Tasmania and overwintered in all stages. Life tables were prepared for *C. thysanura* populations at all study areas and Varley and Gradwell's key factor analysis used to determine that predators and parasitoids were key mortality factors by acting on late nymphal stages. Other factors such as quantity and quality of available food plant and oviposition sites, intraspecific competition, emigration, cultural practices including pruning of terminal shoots, and harvesting of boronia flowers also modified *C. thysanura* populations.

The results of the population study suggested that the absence of key mortality factors through indiscriminate and ill timed applications of insecticides enabled *C. thysanura* populations to reach high densities at which levels they destroyed the plant habitat.

An integrated pest management (IPM) programme was developed for *C. thysanura* using a low dosage of mevinphos insecticide applied as a stem spray rather than as a foliage spray at the peak of the *C. thysanura* late nymphal stage. The application of mevinphos stem spray conserved parasitoids, which were then pupating in the mummified nymphs, by minimizing contact effects while killing the active host on the boronia plant and this reduced host density to a level where the natural enemies could act effectively to bring psyllid populations to non damaging levels. As a result the number of insecticide applications was reduced from 10-12 pre study to 3 in the initial stage of IPM programmes. Subsequent levels of parasitism removed the necessity to spray in 1989/90.

Introduction

The genus *Boronia* (family Rutaceae) is endemic to Australia and includes some of the most desirable plants in the Australian flora.

This genus contains about 70 species and one of the more aromatic is *B. megastigma* (Nees), brown boronia (Fig 1). Although native to Western Australia, it is found in most parts of Australia and New Zealand as an ornamental.

The plant is a woody shrub, 1 to 2 metres in height, with trifoliate leaves, 10-15mm in length. It bears strongly scented cup-like flowers which vary in colour from all yellow to dark brown with yellow inside. The flowers develop from the leaf axils and are picked commercially for sale as cut flowers and, in Tasmania, oil for perfume is distilled from the flowers and *B. megastigma* is now an essential oil crop in that State.

Intensive cultivation of *B. megastigma* as a monocrop for the essential oil industry in Tasmania commenced in the early 1980s. A psyllid, *C. thysanura,* became established and caused considerable damage to boronia plants in the field, almost causing the collapse of the industry prior to the start of this study.

C. thysanura was first identified in 1932 on boronia plants in New Zealand and was thought to be of Australian origin, but had not been recorded from Australia until recently when found attacking *B. megastigma* in Tasmania.

This psyllid had not been previously studied. The aims of this study, therefore, with respect to the general subject of this thesis, were six-fold and were achieved in the context of acquired knowledge. The aims were:

1. to determine the most suitable technique for laboratory mass rearing of the insect
2. to conduct detailed studies of the insect's life cycle and behaviour
3. to evaluate psyllid damage to the host plant
4. to assess any insect preference for host plant cultivars, their phenology and factors involved in tolerance or resistance to the insect
5. to study in detail the population dynamics of the psyllid and
6. to develop a control programme with minimal effects on natural enemies and oil quality.

Fig.1
Boronia megastigma in flower.

Through key factor analysis (Varley and Gradwell 1968), the life system for *C. thysanura* was established, an understanding of which led to the development of an integrated pest management programme for *C.thysanura*. The cost effectiveness of this programme on commercial crops of boronia was determined.

Chapter 1

Literature Review

1. Historical background of the family Psyllidae and its relationship to the Aphididae

1.1 Historical background of the family Psyllidae.

A review of literature dealing with the family Psyllidae reveals numerous publications on its initial classification, but most of these are merely economic listings. Included in the review are those works which stress original work or which contain information of the greatest utility to future workers.

Reaumur (1737), as quoted by Froggart (1900), originally named the psyllid family "Faux Pucerons" from their relation to the Aphididae. Other workers placed them in the genus *Chermes* (now restricted to a group of coccids) and *Psylla*, a Greek word for a flea in reference to their jumping powers. The Psyllidae since then has been described in many papers, but it was not until 1848 that any regular classification of this family was undertaken.

Foerster (1848) defined different genera, several new ones, redescribed the old species, and described a great number of others. Low (1878) divided the Psyllidae into four subfamilies and then published a complete revision of all the described palaearctic species with their synonomy followed by a catalogue of over 170 species. The members of the family Psyllidae have a wide geographical range. Europe is particularly rich in species; and they are well represented in southern Asia, North and South America and Africa.

The only appreciable work that has been done on the Psyllidae of Australia is that of Froggatt (1900, 1901 and 1903). Froggatt named over 60 species and established nine new genera. His system of generic arrangement was based on that developed by Low (1878) in which the genera were distinguished entirely on the venational

characteristics of the wings. Froggatt placed a large number of species in *Rhinocola* and *Aphalara*, genera which apparently do not occur in Australia (Tuthill and Taylor 1954). Froggatt's work was reviewed by Tuthill and Taylor in 1954 by examining his type specimens of Psyllidae and an attempt was made by the two workers to bring Froggatt's classification of the family in line with the world fauna. Species originally assigned to *Rhinocola* and *Aphalara* by Froggatt are now placed in *Creiis* (Scot), *Eucalyptolema* Froggatt, *Cardiaspina* Crawford, *Ctenarytaina*Ferris and Klyver and *Spondyliaspis* Signoret.

Of the species of *Ctenarytaina* described from New Zealand in 1932 by Ferris and Klyver, *C. thysanura* was certainly of Australian origin, although it was not recorded from Australia until recently when they were found attacking *B. megastigma* in Tasmania. In New Zealand, *C. thysanura* had been found on *Boronia* sp.

Psyllids are small, 2 - 5mm in length and usually resemble miniature cicadas in form. They have strong jumping legs and relatively long antennae. The adults of both sexes are winged and the beak is short and three-segmented. The nymphs of many species produce large amounts of a white waxy secretion, causing them to superficially resemble the woolly aphid.

1.2 Relationship of Psylloidea to Aphidoidea

The Psylloidea evolved from a proto-homopteran ancestor as a late Permian branch of the main aphid-coccoid stock (Evans 1963). Cytological evidence by Bhattacharya (1972) and Suomalainen and Halkka (1963) support the view of Heslop-Harrison (1956) who argued that the male genitalia and the presence of a complicated gut filter chamber brings the psyllid closer to the main Cicadoid-Jassoid stem.

According to Hodkinson (1974), psyllids are functionally different from aphids in that they are monomorphic, have obligatory sexual reproduction, are oviparous and possess a highly developed gut filter chamber, whereas aphid species are often additionally polymorphic, parthenogenic and viviparous.

2. Developmental biology of Psylloidea

The development of every insect involves three major stages namely the embryo, the immature instars and the adult. Embryonic development occurs within the egg which is well supplied with yolk and surrounded by a delicate outer shell or chorion. Following hatching or eclosion, the insect feeds and grows, moulting several times until the adult reproductive stage is reached.

All psyllids pass through an egg and five nymphal instars before becoming adult. Bhattacharya (1972) and Walton (1960) reported that psyllids are strictly bisexual, with the male the heterogametic sex. An exception is *Psylla myrtilli* (Wagn.) which is claimed to be parthenogenetic (Lauterer, 1963). The external sex organs appear post-embryonically and develop continuously throughout the nymphal stages (Zucht 1972). By the fifth instar both male and female nymphs are morphologically distinct (Hodkinson 1973a; Ball and Jensen 1966; Ossiannilsson 1970). Burts and Fischer (1967), working on pear psylla, reported that in adult females, maturation of eggs may occur quickly and oviposition can commence within five days of emergence. However, females which hibernated probably delayed egg development until spring. Takara *et al.* (1986) reported a pre-oviposition period from 1 - 3 days for *Heteropsylla cubana* (Crawford), a psyllid attacking *Leucaena leucocephala* (Lam.) in Hawaii.

2.1 Life Cycle features of Psylloidea

Atwal *et al.* (1970) and Pande (1972) reported that under tropical conditions, generations are continuous throughout the year, but the growth rates are governed by prevailing climatic factors and the condition of the host plant. Psyllids have evolved mechanisms to survive the winter period when the host plant is dormant and they are recorded as overwintering in all life stages in north temperate and arctic regions (Vondracek, 1957). Overwintering diapausing eggs are usually laid on the dormant buds of the host plant by *Psylla mali* (Schmidt.) while overwintering nymphs inhabit favourable microclimates on the host plant such as beneath bud scales (by *P. ambigua* Forst.), in leaf axils (by *Strophingia* sp.) or on the underground stolon rosettes of perennial plants (by *Craspedolepta* sp.). Two basic forms, summer and winter, have

been identified in *Psylla pyri* (L.) (Kharizanov, 1969). In *P. pyri*, adults enter diapause to overwinter on the host plant. Diapause is induced by low temperature/short photoperiod (Thanh-Xuan 1972b) and the resulting forms are morphologically distinct from adults produced in summer (Bonnemaison and Missionnier 1955, 1956). Wong and Madsen (1967) and Oldfield (1970) investigated the influence of photoperiod and temperature on diapause in *P. pyricola* (Forster) in California. The conditions they used to produce summer and winter forms were a 16-hour photoperiod at 25°C and a 11-hour photoperiod at 17°C respectively. The summer forms were generally of lighter colour and winter forms darker and larger. These two forms, according to Wong and Madsen (1967), differed biologically as well as morphologically. The summer female was able to oviposit within a week after adult emergence whereas the overwintering female had an ovarian reproductive diapause. In British Columbia, Wilde and Watson (1963) reported that low temperatures were required for termination of diapause in *P. pyricola*. They also reported a definite ovarian diapause in overwintering females.

The development of two forms in *P. pyri* was shown to be directly dependent on photoperiod and the reproductive diapause in *P. pyri* was induced by exposing fifth nymphal instars and adults to a short photoperiod (Bonnemaison and Missionnier 1955). It was also found that a 12-hour photoperiod produced the longest diapause which was further lengthened by exposure to high temperatures. Low temperatures decreased the length of diapause and nutrition apparently had no effect on its termination. An aestival-autumnal-hibernal reproductive dormancy as an adult has been reported for *Euphyllura phillyreae* (Forst.), a psyllid which infests olive trees in Greece (Prophetou-Athanasiadou and Tzanakakis 1986). Hoffmann *et al.* (1975) noted that *Acizzia rusellae* (Forst.) nymphs in summer are much lighter in colour than winter forms. They presumed that this was meant to minimize heat uptake from the sun. Very few species of psyllid overwinter as adults on their host plant; most disperse onto shelter plants, particularly conifers, and move back onto their true host plant to mate and oviposit in the spring, usually prior to bud burst (Schaefer 1949). No knowledge of the biology and ecology of *C.thysanura* has been reported to date.

2.2 Biology of the immature stages

2.2.1 Egg

There is extensive literature on the water relations of insect eggs (Edney 1957; Hartley 1965), but relatively little attention has been paid to those eggs which are inserted into plant tissues and less still, psyllid eggs. Psyllid eggs all possess a basal pedicel which is inserted into the host plant tissue. Water is taken up from the plant through the pedicel and eggs quickly desiccate if the water source is removed (White 1968a). Van der Merwe (1923) and Clark (1962) recorded that eggs collapse and do not hatch if the tissue on which they are laid dries out. Some authors, Wilcke (1941) and White (1968a), maintain that psyllid eggs possibly derive nutrients as well as water from the host tissues. Wilcke (1941), although not advancing any evidence to support the hypothesis, considered that the work done on water absorption by insect eggs does not eliminate the possibility that dissolved materials may also be taken up. Eggs of *H. cubana* are deposited on new terminal growth and are attached by a stalk inserted into the leaf surface, through which fluids are taken up from the host plant, since removal of the egg causes it to shrivel within a day (Takara *et al.* 1986). Catling (1971) reported that physiological changes in leaf tissue may affect the mechanism of water absorption. Eggs can be laid superficially on a leaf or bud surface (*Paratrioza cockerelli* Sulc.), be deeply embedded in the plant tissue (*Arytaiana spartii* Guer.) or laid in leaf axils (*Strophingia ericae* Curt.). Eggs laid in protected situations suffer less predation than those laid superficially (Watmough 1968a).

2.2.2 Nymph

Many data suggest that psyllid nymphs are highly susceptible to desiccation, particularly at high temperatures, and that this is an important factor contributing to population control (Atwal *et al* 1970; Catling and Annecke 1968; Green and Catling 1971). Not surprisingly, nymphs are most susceptible to desiccation at the moult when the ability to retain water is reduced (Hodkinson 1973b: Pletsch 1947). Marshall (1959) reported that hot, dry weather is injurious to the psyllid, *P. pyricola*; however, the most vulnerable ones were the freely moving fourth and fifth instar nymphs which were killed, presumbly by desiccation, but nymphs in the earlier stages died as a result

of the solidification of honeydew within which they fed.

Moreau and Robert (1985) emphasised that cold weather alone seldom causes heavy mortality of indigenous pests owing to such adaptive behaviour as diapause, although it may kill species newly introduced to a climatic region to which they are not yet well adapted. It was also found that the differential effects of cold weather on pests and their parasitoids could cause a temporary increase in pest populations. However, repeated cold spells alternating with mild ones during which overwintering insects resume activity can cause severe mortality, for example, to cereal aphids and some psyllids. Van der Merwe (1941) also noted high mortalities among nymphs of *Trioza erytreae* (Del Guercio) during hot summer days in Durban while in cooler weather the insects thrived

An inverse relationship established between temperature and psyllid populations has been reported by List (1939); Madsen *et al.* (1963); Clark (1964); Moran and Blowers (1967); and Catling (1969).

Catling (1969), based on *in situ* counts of *T. erytreae* colonies on citrus in the field, concluded that a saturation deficit of 26mm Hg was critical for the survival of this species, but the direct effect of temperature on the insect, especially the nymphal instars, and the role of the host plant remained unresolved. In the case of *A. russellae,* Hoffmann *et al.* (1975), reported that it was likely that direct short term temperature effects were responsible for a fall in psyllid population numbers. Furthermore, very effective cooling of the host plant, *A. karroo,* ensured that the leaf temperatures of the host plant did not exceed ambient air temperatures even in strong sunlight, so that *A. russellae* nymphs showed no symptoms of temperature stress on the host plant even at temperatures of 35°C in strong sunlight and made no attempt to seek shelter in the shade under the leaves. Seemingly, *A. russellae* and the host plant are admirably adapted to withstand higher summer temperatures.

Evaporative cooling by plants (Heinckel 1964; Collier *et al.* 1973) and by insects (Mellanby 1932; Gunn 1942; Farnworth 1972; and Wigglesworth 1972) is a well known phenomenon, but few attempts have been made to relate these effects to survival of sapsucking homopterans at critically high temperatures in the field or laboratory. Broadbent and Hollings (1951) determined the influence of heat on five species of

aphids, after short exposures of sixty minutes and showed that survival of the aphids was greater on the host plant. It was concluded that aphids presumably can cool themselves by evaporation when feeding. Furthermore temperatures on the surfaces of the transpiring leaves are lower than that of the air and these lower temperatures will aid survival. In addition, the dorsoventral flattening of nymphs gives them a high surface area to volume ratio and hence a high potential for water loss. However, psyllid nymphs have evolved various mechanisms by which water loss is reduced.

In *Cardiaspina densitexta* (Taylor) hatching of first instar nymphs is controlled by a combination of light/dark periodicity and early morning temperature; nymphs emerge just after dawn and thus have time to settle and begin feeding before they are exposed to the effects of high temperature/low humidity (White 1968b).

In some Australian species of the family Spondyliaspidae, North American *Euphalerus* sp. and in one *Pachypsylla* sp., the nymph forms an enveloping protective lerp or nest from the honeydew (or wax?) which it produces (Miyatake 1968; Russell 1971; White 1971). Certain species e.g., *Trioza fletcheri* (Crawford) live in the mesophyll tissue of the host plant (Bindra and Varma 1969) while other species live in the humidity-buffered environment of a roll leaf gall (Thanh-Xuan 1970). Those species living in protected situations such as leaf axils e.g., *Aphaleura floccosa* (Patch), produce a lot of flocculent wax threads (Patch, 1909) while in some tropical, free living forms, such as *Swezeyana* sp., the nymph is completely covered in a characteristic meshwork of wax filaments (Tuthill 1966).

Madsen *et al* .(1963) noted that the absence of new growth and the poor condition of the foliage caused a steady decline of pear psylla numbers in abandoned orchards in California. This would not be a factor in commercial orchards where proper cultural practices are used, but may be a limiting influence on the survival of pear psylla in abandoned pear trees.

2.3 Adult biology

2.3.1 Dispersal

Johnson (1969) reported that dispersal of insects by flight forms an integral part of their population dynamics. When dispersal by flight of the insects is related to density,

as reported by Watmough (1968a) and Dempster (1968), for broom psyllids,and Walof and Bakker (1963) for broom mirid, density must be considered along with the other processes that not only alter, but regulate populations of insects.

The ability of adult psyllids to fly any distance under their own power is very restricted (Clark 1962). However, psyllids disperse long distances in air currents, and Glick (1939) records *P. cockerelli* as a significant component of aerial plankton. Long-range dispersal (up to 13 km) by wind is most apparent in the north temperate species which disperse in the fall to seek shelter plants on which to overwinter (Hodkinson 1972); wind assisted dispersal over short distances up to 200m is common in many species (Clark 1962; Rasmy and Macphee 1970; and Watmough 1968b).

Lewis & Taylor (1965) reported that most of the Hemiptera and Auchenorrhyncha are day flyers. Waloff (1973) also reported that in most species of Auchenorrhyncha, both males and females fly in equal numbers and that weather conditions, especially temperature, play an important role in the flight activity of leafhoppers.

2.3.2 Mating and Oviposition behaviour

Englemann (1970) observed that a ratio of 1:1 between male and female individuals in a population was common among insects. This ratio was accomplished by both major sex-determining mechanisms, balance between male and female sex determiners and epistatic sex determination. In many species of psyllids, mating is a straight forward act in which the aggressive male approaches the passive female from the side, rotates its abdomen and grasps the female valves with its parameres before inserting the aedeagus (Cook 1963). However, in *C. densitexta*, there is a well-defined precopulatory behaviour pattern in which the males repeatedly attempt to copulate, but the female repels them (White 1970a). Burts and Fischer (1967) in their studies of the mating behaviour of *P. pyricola* also reported that males were the aggressors in mating with a capacity of mating about once a day through the first 2 weeks as adults. Females remained fairly passive in the mating act and did not respond to the advances of the males.

Many psyllids stridulate (Campbell, 1964; Heslop-Harrison, 1960) and this may serve to bring the sexes together, particularly at low densities (White, 1970a). The

duration of single copulations varied from less than one minute to 3 or 4 hours and averaged 36 minutes (Burts and Fischer 1967). In most species, it lasts no longer than 30 minutes (Pande 1971; White 1970a). Mating takes place most frequently in the early afternoon when it is warmest and brightest and to produce fertile eggs at full capacity a female has to mate repeatedly at least every 10 days. However, each male is capable of fully inseminating four females. Egg fertility of fully-mated female *P. pyricola* approached 100% for a large part of the egg laying period but declined to 75% towards the end (Burts and Fischer 1967).

In *Arytaina* spp., the number of eggs laid per female appeared to be related to the degree of predation of eggs (Watmough 1968a).

3. Psyllid feeding and its effect on plant growth

The effect of an insect infestation on a plant stand is a product of two opposing processes: feeding rate of the insects and the growth rate of the plant. An example of the complex interaction of these processes for various cruciferous plants and two different pests is given by Taylor and Bardner (1968a and b).

Insect defoliation of trees affects the growth rate and is reflected in the annual growth rings (Mott *et al.* 1957; Varley and Gradwell 1962; Lessard and Buffam 1976; Creber 1977), whilst aphids may also affect the time of leaf fall and other characteristics (Dixon 1971).

Psyllids, like aphids, are phloem feeders (Clark 1962; Eyer 1937; Hodkinson 1973a; Woodburn and Lewis 1973). Adult feeding causes little damage to the host plant and feeding damage is usually attributable to the nymphal stage (Annecke and Cilliers 1963; Clark 1963a; White 1970b). In Western Samoa, large *Leucaena* trees have died following repeated defoliation over a period of more than 10 months by *H. cubana* (Thomas and Liebregts 1987). Richards and Brooks (1958) reported that the feeding damage to the host plant which is attributable to only nymphal feeding may be associated with the degeneration of mycetome and associated symbionts in the adults. White (1970b) suggested that adults have a lower requirement for nitrogen than do growing nymphs so that increasing the proportion of nitrogen in the food is not critical. However, females which continue to develop and lay eggs over a long period would

certainly require a high quality nitrogen source. Nakahara and Lai (1984) also reported that where psyllid damage to the host plant is not so extreme, flowering may be prevented and no seed set and that the effect was particularly serious under dry conditions.

Severe infestation of potato by *P. cockerelli* was characterised by "the upward curling and yellowing of the older leaves, the purpling of the margin of the younger leaflets, enlargement of the nodes and petioles, rosetting and production of axillary shoots and tubers" (Eyer 1937). Furthermore, there is a reduction in nitrogen and pigment concentration of infested plants (Eyer 1937). Hodkinson (1973b) also reported that feeding damage by most species is not severe and *S. ericae* at field densities has no measurable effect on dry matter accumulation, shoot length, nutritive status and flower production of *Calluna vulgaris* (L). In *P. mali* nymphs, the stylet bundle is directed into the plant tissue by the stylet muscles and not by labial movement (Pollard 1970).

Psyllids are able to actively locate suitable plant tissue by the innervation of the mandibulary stylets (Forbes 1972). Feeding damage and gall formation can be traced to a systemic toxaemia caused by salivary injection (Williams and Benson 1966), and Walton (1960) demonstrated the presence of permanent salivary sheaths in the plant tissue. Although there is no evidence confirming disease transmission by *H. cubana* (Nakahara and Lai 1984), psyllids are known vectors of viral and bacterial diseases of plants including citrus leaf-mottle yellows disease (Martinez and Wallace 1967), greening disease of citrus (McClean and Oberholzer 1965; Schwarz *et al.* 1970), pear decline condition (Jensen *et al.* 1964) and fireblight of pears (Wilde *et al.* 1971). The exact mechanism of disease transmission is not understood, but Wilde (1971) concluded that *P. pyricola* does not act as a reservoir for fireblight and that direct access to the bacteria is necessary for transmission.

4. Population dynamics of Psylloidea

Planthopper populations fluctuate dramatically within and among seasons in the same patch as well as spatially among patches (Denno and Grissel 1979; Wallof 1980). Population growth can be exponential during the growing season (Denno *et*

al. 1981; Kiritani *et al.* 1972) and particularly rapid in local patches where aggregations of brachyterous adults occur (Kisimoto 1965). Denno and Roderick (1990) reported that numerous factors, including predators, parasitoids, host plant nutrition, dispersal, competition etc influence population growth and detertmine spatial and temporal variation in population size of plant hoppers.

In Australia the most intensive studies of psylloid ecology have been upon *C.albitextura* which causes leaf necrosis in its food plant. These studies Clark (1962-64) were completed in savannah woodlands of *E.blakelyi* near Canberra. White (1966) also used *C.densitexta* for his research into the causes of pest outbreaks in savannahs of south-eastern South Australia. Clark and Dallwitz (1974) followed the population fluctuations of four other spondyliaspids associated with *C.albitextura* on *E.blakelyi.*

Morgan (1984) reported that most Australian species are multivoltine with generation times varying according to the temperature of any locality. He said that while temperature may directly affect voltinism, there are species which appear to be univoltine or bivoltine in most parts of their distribution, an example is *Schedotrioza* sp. Where voltinism is influenced by temperature, affected species may respond by producing an additional generation in warmer than average winters or springs, thus beginning outbreaks.

4.1 The natural enemies of Psylloidea

4.1.1 Predators of the Psylloidea

Psylloidea as a group are preyed upon by birds, insects, spiders, mites and lizards (Morgan 1984). According to Morgan (1984) the insects that preyed on the psyllid species in Australia are mainly syrphid (hover) flies, coccinellids, lacewings, mantids and mantispids, spiders and the common ants *Iridomyrmex* spp.

In general, psyllid predators show little specificity and either opportunistically exploit psyllids when they are available, or otherwise, utilise aphids or other prey. Predator populations are often poorly synchronised with, and slow to respond to, changes in psyllid populations although, under certain conditions, a degree of natural control over pest species has been achieved (Catling 1970; Clark 1963d; Nickel *et al.*

Table 1

Predator complexes of six psyllid species selected to represent varying nymphal habits and geographical locations.

	Heteropsylla cubana Hawaii	*P. cockerelli* N.America	*Arytaiana sp.* Britain	*Trioza erytr-ae* S.Africa	*Psyllopsis fraxini* Britain	C. *albite-xtura* Australia
Hemiptera						
Miridae	+	-	+	-	+	-
Anthocori-dae	+	+	+	+	+	-
Lygaeidae	-	+	-	-	-	-
Nabidae	-	+	-	-	-	-
Reduviidae	+	-	-	-	-	-
Dermaptera	-	-	+	-	-	-
Diptera						
Syrphidae	+	+	+	+	+	+
Neuroptera larvae	+	+	+	+	+	+
Coleoptera						
Coccinellidae	+	+	+	+	-	+
Hymenoptera						
Formicidae	-	-	-	-	-	+
Arachnida	-	-	-	-	-	-
Acarina	+	-	+	+	-	+
Phalangida	+	-	+	-	-	-
Araneida	+	-	+	+	-	+

(from Nakahara (1986),Dempter(1968), Hodkinson and Flint (1971),Clark (1964 b,c),Catling (1970),Hodkinson (1974)

1965). A possible exception may be *Anthocoris sarothamni* (Dgl and Scot.), a predator of *Arytaina* sp. in Britain, which feeds selectively on psyllids and which has a higher fecundity and longevity when fed on psyllids in preference to aphids (Anderson 1962; Dempster 1963). The predatory bug, *Paratriphleps laevisculus* (Champion) preys on nymphs and eggs of *H. cubana* and it also attacks the same stages of *Heteropsylla huasachae* (Caldwell) on *L. leucocephala* in Hawaii (Nakahara 1986). Before the arrival of the leucaena psyllid, *P. laevisculus* had been recorded attacking thrips in leucaena flowers. Other predators apart from coccinellids did not appear to play a significant role in controlling *H. cubana* (Funasaki 1985a,b,c; Nakahara and Lai 1984). Westigard *et al.* (1968) reported that a degree of natural control over pest species has to be achieved under certain conditions with predators on pear psylla in Southern Oregon.

4.1.2 The parasitoids of Psylloidea

Insect parasites (parasitoids) are a special form of predator that usually require only one host (prey) for development into a free-living adult and are often the same size as the host (Stehr 1974).

In a comprehensive review of the parasitoids of Psylloidea (Jensen 1957), the order Hymenoptera with eleven families (Encyrtidae, Eulophidae, Eupelmidae, Eurytomidae, Pteromalidae, Thysanidae, Torymidae, Cynipidae, Braconidae, Ceraphronidae and Platygasteridae) contained the most important parasitoids followed by the family Cecidomyiidae (order Diptera).

Morgan (1984) reported that the main parasitoids of Australian Psylloidea comprised a complex group of Encyrtidae and Eulophidae with black or metallic green adults, mostly placed in the genus*Psyllaephagus*. Morgan(loc cit) reported that (a) parasitism was most often recorded on late nymphal stages especially in areas where psyllid populations had been at moderate to high densities for several generations and (b) parasitism of psyllid late nymphal stages was often also recorded in low density populations following outbreak. There is no record of parasitoids attacking psyllid eggs. The genera *Lestodiphosis* and *Bremia* (family Itonididae) are normally

considered to be predatory in habit since records of their attack on Psylloidea are inconclusive and inadequately understood (Jensen 1957). Lal (1934) listed *Lestodiphosis* and *Bremia* as parasitoids of adult psyllids, but Rubsaamen (1901) definately stated that it attacked psyllid nymphs. Gall midges (genus *Endopsylla*) are endoparasitic in adult psyllids (Jensen 1957; Lal 1934). Nymphal parasitoids were exclusively hymenopterans with the exception of *Sectiliclava cleone* (Wlk) reported to parasitize adult *P. melanoneura* (Forst) (Robinson 1961a,b,c). However in most instances wasps attack the nymphal stages.

The parasitoid species recorded from the Psylloidea appear to be almost exclusively restricted to psyllids with specific parasitoid-host relationships (Jensen 1957). Although it is known that hymenopterous parasitoids attack psyllid nymphs, little is known about psyllid-parasitoid relationships (Moran *et al.* 1969; Onillon, 1969; Catling 1969b; Clark 1964a). In addition, hyperparasites may limit the effectiveness of primary parasitoids (McDaniel and Moran 1972). In species of *Tetrastichus* (Eulopidae), the two sexes develop differentially from parasitized nymphs of different instars; only males emerge from fourth-instar nymphs,while both males and females emerge from fifth nymphal instars (Hodkinson 1973a; Onillon 1969; Pletsch 1947; Moran *et al.* 1969).

4.2 Intraspecific competition in Psylloidea

Watmough (1968a) reported that in *Arytaina. genistae* (Latreille) and *A. spartiophila* (Forster) nymphal mortality is density dependent at high densities and crowded nymphs produced slightly smaller adults in *A.spartiophila* and *A.genistae.* He found that, at high population densities, most nymphs settled on exposed portions of the leaves, making them vulnerable to predators and weather and that the infested plant was weak and stunted,so that they were competing against each other for both food and space. He also reported that intraspecific competion in broom psyllids during the nymphal and adult stages resulted in emigration of the the adults accompanied by a reduction in fecundity if emigration fails to reduce the psyllid population. Clark (1963b) also reported that intra specific competition for food and oviposition sites occured in *C. albitextura* nymphal and adult stages. This led to emigration of adults but

emigration was apparently less important than the reduction in fecundity in adjusting the psyllid population. Varley *et al.*(1973) said that to assess the effect of competition, one must (1) measure changes in the supply of resources, (2) measure the number of individuals competing and (3) assess the negative influences which may result in either a reduction in the number or proportion which survive, or a reduction in the growth rate, adult rate or reproductive capacity. In *C. densitexta,* White (1970b) found that nymphal mortality decreased with increasing density up to a certain density, beyond which mortality increased rapidly. He again postulated that group feeding, up to a certain density, caused a disproportionate breakdown of plant tissues which enhanced the food supply to the individuals. In addition a parallel situation existed with adult fecundity was proposed. Clark (1963c) and Thanh-Xuan (1973) also reported that female fecundity decreased in a density dependent manner with increasing density. However, at low densities, fecundity and life span of adult female *P. pyri* increased with increasing density (Thanh-Xuan 1971).

4.3 Host plant range and host specificity of the Psylloidea

4.3.1 Preferred hosts

Ehrlich and Raven (1964) suggested that the plant-herbivore interface may be the major zone of interaction responsible for generating terrestrial organic diversity. They considered that the origins of organic diversity in the reciprocal selective responses between closely linked organisms have been vastly under-rated. Reviews of host selection and preference by phytophagous insects were provided by Dethier (1954), who discussed the evolution of specificity, and Thorsteinson (1960), who outlined the steps involved in food plant recognition.

In considering host plant specificity in psyllids, distinction must be made between nymphs and adults. The latter are more catholic in their feeding habits and may feed on plant species unsuitable for nymphal development. Thus, adult *P. cockerelli* are recorded from 54 plant species in 11 families, whereas nymphs are recorded only from the Solanaceae (Pletsch 1947). In Hawaii, *H. cubana* has been collected from all 10 recognised species of the genus *Leucaena* (family Mimosaceae) which, together with

some hundreds of *Leucaena* sp. crosses and cultivars, are grown in the Agricultural Plant Pest Control branch (Hawaii U S A.) Experimental Station (Brewbaker 1983).

In this study, a host plant is defined as a plant species on which a psyllid is able to fully complete its development. This definition is true for *H. cubana* and other Psylloidea because, in Hawaii, *H. cubana* also occurs on two other tree species, *Debonix regia* (L) and *Prosopis pallida*(Willd.) belonging to the Mimosaceae, but on these species, nymphal development does not proceed beyond the first instar and so the species are not true hosts (Nakahara and Lai 1984). The host plant range of the psyllids is restricted almost exclusively to the perennial dicotyledonous plants (Eastop 1972). The exceptions include the small family Liviidae and perhaps *Psylla bagnalli* Heslop-Harrison (Hodkinson 1974) which occur on the monocotyledonous genera *Juncus* and *Carex.*

Exceptions to this trait exist, but they are generally species such as *P. cockerelli* and *Trioza nigricornis* (Forst) which have extended their host plant range as a result of man's agricultural activity (Eyer and Crawford 1933). Furthermore, closely related species usually occur on closely related host plants; for example, the holarctic *Pachypsylla* spp. occur on *Celtis* spp. (Miyatake 1968). Morrow (1977), in detailed surveys of insects attacking eucalypts, in south-eastern Australia found that 63 per cent of the collected phytophagous insects (grazers and sapsuckers) collected attacked one eucalypt species, 30 per cent attacked two species and eight per cent only fed on all three species. An exception to this rule might appear to be the type genera *Psylla* and *Trioza* which display a worldwide distribution on a variety of host plants and an extension of their host range on to distantly related plants: *P. mali, P. peregrina* and *P. sorbi* are restricted to the Rosaceae, whereas the closely related *P. ulmi* occurs on *Ulmus* in the Ulmaceae (Heslop-Harrison 1948).

Heslop-Harrison (1937) found that certain psyllid species display host plant divergence throughout their host range. In British Columbia, *P. sorbi* feeds on *S. americana,* while in Europe it feeds on *S. aucuparia.* Moore (1970a,b), from a study of the relationships of the Australian eucalypt-feeding genus *Glycaspis* (Taylor), suggested modifications to the taxonomy of the eucalypts based on psyllid-host plant relationships. Thus, Hodkinson (1974) stressed that psyllid evolution at the species

level has followed fairly closely the evolution of higher plants and that host plant specificity, if used carefully and if due allowance is made for possible disjunct host range extension, can be a useful tool in predicting the relationship of the psyllid and vice versa.

4.3.2 Effects of host plants on psyllid development

The effects of host plants on psyllid development can be manifested in two ways: namely as developmental differences between host plant species and as developmental differences within host plant species. Within the geographic range of a host species, certain plants can be more favourable than others (Moran 1968a; Pande 1972). Pletsch (1947) reported that fecundity and nymphal survival in *Paratrioza cockerelli* are highest on potato and tomato, but are much lower on egg plant and pepper.

In *S. ericae* ,Hodkinson (1973a) said that only 20 per cent of the ingested phloem sap is assimilated and the honeydew excreted is almost pure carbohydrate. This suggests that the phloem sap is not a highly nutritious food source and that changes in the quality of sap, particularly changes in amino acid concentration, should accelerate psyllid development. Even within a single host plant species, favourability for psyllid development is directly related to the quality of the available plant sap. Increases in soluble nitrogen sources in plant tissues associated with water stress on the host plant (Catling 1969c; White 1969) and flushing of new growth (Catling 1971; Pande 1972) enhance both nymphal survival and growth rates, while decreases in soluble nitrogen due to ageing of leaves causes reduced fecundity and a shorter life span in *P. pyri* (Thanh-Xuan 1972a). In *S. ericae,* the length of the life cycle appears related to the nutritional status of its host plant, with psyllids living on nutrient-deficient plants having a greatly extended life cycle (Hodkinson 1973a). There is also evidence that younger more vigorous plants perhaps with a higher nitrogen content support higher psyllid populations than older plants (Catling 1969a; Watmough 1968a).

4.3.3 Host plant selection in psyllids

Among the factors which result in the selection of a plant, sensory stimuli from the plant are considered to be the most important and their role has been considered from

time to time in various reviews and symposia (Thorsteinson 1960; Schoonhoven 1968; Dethier 1970; and Jermy 1976). Saxena (1969) divided the factors determining the differences in establishment of leaf hoppers on different plants under otherwise identical conditions into two main categories, namely, (1) responses of insects to plants, and (2) plant characteristics determining these responses. The responses of the insects considered to be involved in the six stages of establishment of the insects are (1) orientation, determining the arrival of the insect on a plant, (2) feeding, (3) metabolic utilisation of food, (4) growth, (5) survival and egg production, and (6) oviposition. The plant characteristics determining the above responses by the leaf hoppers, which has been examined by Saxena (1969), include hairiness (Hussain and Lal 1940; Painter 1951; Wolfenbarger and Sleesman 1961a,b; and Broersma *et al.* 1972), and moisture content (Afzal and Abbas 1943).

The mechanism of host plant selection by adult psyllids is unknown, but the innervation of the mandibulary stylets suggests that it is most probably chemo-gustatory. Moran (1968b) reported that *T. eryteae* females were able to differentiate between leaves of different food plants in multiple choice feeding experiments, but in olfactometer experiments, adults failed to respond to the stimuli of different leaf extracts. The lack of response of the psyllids to chemical extracts may be an indication that nutritive factors in the leaves play a primary role in host plant selection in this species (Schoonhoven 1968) and that the host plant selected is not necessarily the most favourable for nymphal development (Moran 1968a,b).

4.3.4 Mechanism of plant resistance to insect attack

Much of the wide acceptance of Painter's classification of the mechanisms of plant resistance to insect pests stems not only from its simplicity and apparent generality, but also because it accurately describes insect and plant responses. Based on previous work, Painter (1936, 1941) proposed that plant resistance, as observed in the field, could be explained by three fundamental mechanisms, namely, (a) non-preference, (b) antibiosis, and (c) tolerance. Painter (1951) and many subsequent workers stressed the fact that these mechanisms are most frequently interrelated although they may also operate independently.

As defined by Painter (1941), preference or non-preference denotes a group of plant characters and insect responses that lead to either movement towards or away from a particular plant or variety for oviposition, food and/or shelter.

The term, "antibiosis", was proposed by Painter (1941) for those adverse effects on the insect's life history which result when an insect exploits certain resistant host plant varieties for food.

A third mechanism, tolerance, was defined as the ability of certain plants to grow and reproduce or to repair injury to a marked degree in spite of supporting a population approximately equal to that damaging a susceptible host (Painter 1951). Modern co-evolutionary theory supports the view that the former two categories represent mechanisms of resistance much different from tolerance. Beck (1965) stressed this difference by excluding tolerance from his review of host plant resistance.

The term, "non-preference", was changed to "antixenosis" from the Greek word "xenos" meaning a "guest", i.e., something that keeps a guest away, by Kogan and Ortman (1978). The reason for the objection to the term, "non-preference", was that it is incongruous with the process it is meant to describe.

Saxena *et al.* (1974) in their studies into patterns of relationships between *Empoasca devastans* (Distant) and *E.kerri motti* (Pruthi) on six test plants, namely, *Gossypium hirsutum* (L) ,*G.herbaceum* (L),*G.arboreum*(L), *Solanum melongena* (L),*S.tuberosum* (L), and *Ricinus communis* (L), reported that a plant may be better than another for weight gain of the leafhoppers but not for their moulting and metamorphosis,and that a plant which is good for weight gain of the insect but poor for moulting and metamorphosis would not enable the nymphs to rapidly establish large numbers of adults on a plant as the plant which is good for moulting and metamorphosis but poor for weight gain. Saxena *et al.* (1974) developed a"growth index" which was calculated as the ratio of the percentage of leafhopper nymphs completing development relative to the developmental period. This index, which represents the capacity of the insect to moult and metamorphose to the adult,was more reliable than weight gain when considering the suitability of plants for the growth of the insects.

Kogan (1974) reported that certain morphological characteristics of the host plant

such as succulence, toughness, pilosity and presence of thorns or spines were factors whose presence could act as barriers to normal feeding or oviposition. Moran (1968) established that *T. erytreae* adults showed a feeding and ovipositional preference for the young leaves of lemon, *C. limon*, over leaves of their indigenous host plants, *Vepris undulata* (Th.) and *Clausena anisata* (Willd.), which provided the nutritional needs of the immature stages. This draws attention as to whether the physical attribute "leaf hardness", *per se*, in contrast to factors such as vision, chemoreception and nutritional status of the host plant, is a key factor in host plant discrimination by *T. erytreae*. Moran and Buchan (1975) reported that the citrus psylla, *T. erytreae*, did not lay eggs on citrus leaves exceeding a hardness rating of 90g/mm lamina thickness. They said that given a choice between pairs of young lemon leaves of the same size and colour, but of differing hardness (but not exceeding 90 g/mm), the psyllids laid more than twice the number of eggs on the softer of the leaves. Moran and Buchan explained that the choice of the youngest leaves by ovipositing *T. erytreae* was that adequate penetration of the egg stalk into the tissue of the leaf was critically important for the survival of the eggs (Lees 1916; Van der Merwe 1941; Blowers and Moran 1967; and White 1968) and secondly, the nymphs of *T. erytreae* cannot live on mature leaves of the host plant. Pollard (1971), in his study of the action of hemipteran mouth parts in relation to hardness of polyporus and plant tissues, stressed the complexity of physical factors such as elasticity, plasticity, toughness and tenacity as well as hardness. Moran and Buchan (1975) again reported that *T. erytreae* females can withold from ovipositing on relatively hard leaves even though they are acceptable as ovipostitional sites. Clark (1963a), in his findings on the factors affecting the attractiveness of eucalypt foliage for oviposition, concluded that besides leaf age, the position of the growing shoot and the nutritional status of the leaf are important factors affecting oviposition.

In Hawaii, it was noted by Sorensson and Brewbaker (1984) that *H. cubana* does not oviposit on *Leucaena* varieties that have more hairs on the shoot. This means that the physical presence of hairs makes the plant unsuitable for oviposition by *H. cubana* females. Furthermore, there is evidence that younger, more vigorous plants support higher psyllid populations than do older plants (Catling 1969a; Watmough 1968a).

Wilde and Van Schoonhoven (1976) reported free choice ovipositional non-preference of leaf hoppers on bean seedlings and plants. However, Kornegay *et al.* (1986) have also reported ovipositional antixenosis/non preference to leaf hoppers, *Empoasca kraemeri* (Ross) in both "free" and "no" choice experiments on *Phaseoulus vulgaris* (L.) varieties.Suppression of oviposition increased with increasing plant age (Kornegay *et al.*1986).

Sogawa (1982) and Walof (1980) reported that most phloem-feeding planthoppers avoid many allelochemicals that are compartmentalized in the non vascular tissues. For example, silicic acid, a strong feeding inhibitor in *N. lugens* is localized in the parechymal cells of rice where plant hoppers generally do not feed. Few data are available on chemical factors involved in plant defense against planthoppers; most existing information emerges only from studies on varietal resistance in corn and rice (Fisk 1980; Sogawa 1982). However, Morgan (1984) reported that high percentage total phenolics in the leaves of *E. camaldulensis* resulted in population loss of *C. albitextura*. He again reported that there was a higher survival rate of *C.albitextura* first instars when the total phenolics in the leaves was low. Woodhead *et al.* (1980) reported that phenolic acids in corn interfere with settling behaviour and deter feeding in *P. maidis*. Sogawa (1982) reported that oxalic acid present in resistant rice varieties is a strong feeding inhibitor. However, Tingey (1985) reported that physical characteristics (glandular and hooked trichomes) can be effective defenses against cicadellids and should be considered in future studies of plant hoppers.

5. Approaches to the study of insect population ecology

Details of the development of sampling programmes for various insects are given by Morris (1955), Le Roux and Reimer (1959), Harcourt (1961a, 1964), Lyons (1964) and Southwood (1966).

5.1 The selection of sampling unit and size/number.

The selection of the sampling unit and size is an important consideration in the sampling plan. The broad criteria for the selection of a sampling unit have been laid down by Morris (1955). Southwood (1966) also gives a detailed method of sampling

size selection. Ruesink and Kogan (1974), in their discussion on "dispersion and sampling programme", said that the decision on how many samples to take from the field in insect population studies is a subjective decision based on (1) the amount of manpower available for taking and processing samples and (2) the accuracy desired in the resulting data. Thus, the sampling size chosen is, necessarily, a compromise between manpower expended, cost and the accuracy of the results.

As a measure of the relative abundance of each stage, Carne (1966a) suggested that the number of shoot units bearing each stage of the insect being studied could be taken. Hodkinson (1973b), in his study of the population dynamics of *Strophingia ericae* (Curt.), a psyllid, sampled seventy-two *Calluna vulgaris* (L.) shoots at fortnightly intervals and then counted the number of eggs and nymphs present on each shoot. Population estimates of eggs and nymphs of *A. spartiophila* and *A. genistae* were obtained by Watmough (1968a) by sorting through 100 g cuttings of green broom shoots under a binocular microscope. She expressed population estimates as the number per 100 g of green broom or as a total number in the whole study area. However, in her competition experiment in the same study, found that the data appeared more meaningful when population densities were expressed as number per broom bud rather than number per 100 g of broom. Sampling of the populations on broom were carried out twice a week by taking an equal number of cuttings from each row of bushes, with the bushes themselves being chosen at random within rows. Clark (1964a), in his study of the population dynamics of *Cardiaspina albitextura* (Taylor), estimated the number of psyllids on a per shoot basis for each generation by selecting ten host trees in each study area and searching for psyllids at 12 randomly selected points on each tree. He calculated the overall mean number of eggs and nymphal instars of *C. albitextura* per shoot and this gave a satisfactory estimate of the relative abundance of the successive generations. Bray and Woodroffe (1988),and Sorensson and Brewbaker (1986) devised a number of rating systems to allow rapid assessments of *H.cubana* population densities and plant damage because psyllid counts were not possible in the time available due to the large psyllid populations on the *Leucaena* terminals. Stechman *et al.* (1987) developed a technique for assessment of *H.cubana* which used *Leucaena* leaf pinnae as subsamples.The method required the collection

and examination of live plant materials and the psyllids were directly counted. Edler and Mayer (1990) reported that *H. cubana* nymphal population could be assessed by taking whole terminals of the *Leucaena* plant and washing the terminals in 70% alcohol. This method is questionable since psyllid nymphs tend to cling to the terminals with their claws so that the number of nymphs dislodged from the terminals could vary so that this technique is unlikely to provide consistently accurate estimates of the psyllid population. Bray *et al.* (1989) in an attempt to develop a sampling method for *H. cubana* reported that washing terminals in 70% alcohol failed to dislodge all the psyllid nymphs and the likelihood of a psyllid nymph being dislodged increased with instar size,but the proportion dislodged varied between sample dates so that the technique provided inaccurate estimates of the psyllid population. They used other techniques like fumigation of *Leucaena* terminals in acetic acid, the use of ultrasound to dislodge the psyllid eggs, washing the terminals in 70^{o}C water and brushing and fumigation with ethyl acetate but none of these techniques provided accurate and consistent results. Direct counting of psyllids, though time consuming, was the best method used by psyllid workers to achieve consistent and accurate results.

5.2 Population studies

Approaches to population studies have been given by many workers and have been outlined in detail by Clark *et al.* (1967). Many of the difficulties encountered in the methods of Nicholson (1957, 1958) , Andrewartha and Birch (1954, 1960) and Milne (1957a,b, 1962) were overcome by the proposal of the life system approach by Clark (1964c), Geier (1964) and Clark *et al.* (1967). In the study of insect life systems, Clark *et al.* (1967) listed "life table studies", key factor studies and the study of ecological processes as the main approaches.

5.2.1 Life table studies

Varley *et al.* (1973) reported that the understanding of the numerical behaviour of populations is the collection of life table data at one or more sites over several years. In this type of study,according to Liebhold and Elkinton (1988), data is collected on animal density at successive stages and about the impact of specific mortality agents

within a generation and these data are analysed to quantify mortality over specific age intervals. Richards (1940) considered that the number of each instar found in a series of systematic samples corresponds with the time spent in that instar, any deviation from this representing the magnitude of mortality in that stage. Richards and Waloff (1961) also considered the life table to be the keystone of all populaion studies because of its provision of numerical estimates of successive causes of mortality. The most frequently used life table in insect population studies is the "age or stage specific life table" (Southwood, 1966) which is based on the fate of individuals in a particular generation. Richards (1961) adopted the term "budget" to describe an age-specific life table which listed the actual absolute population at different stages and recorded the action of mortality factors where these were known. Watmough (1968a) used the method of Richards (1940) to estimate mortalities of *A. spartiophila* and *A. genistae* on broom. Varley and Gradwell (1968), in their study of the population dynamics of the winter moth, *Operophtera brumata* (L.), constructed the life table of the insect and estimated the age-specific mortalities, which they referred to as "k-values", from which the total generation mortalities were calculated.

Fundamental to the establishment of a life table is an adequate sampling programme that measures the size of the population and the proportion of each stage in it. Richards (1961) stressed that the sampling intervals should be (i) short enough to allow for very rapid growth during some seasons and also for changes in weather, and (ii) regular and prolonged over the whole season so that each form is sampled in proportion to its abundance. The necessity of intensive studies involving continual observation of the insect in the same area has been stressed by Morris (1960) and Varley and Gradwell (1963). These authors said that information is usually required on the population size of each developmental stage of the insect in question so that a life table or budget may be constructed and an attempt made to determine the key factors regulating the population. Morris (1955) also stressed the importance of time and frequency of sampling and stated that the seasonal timing of sampling will be determined by the life cycle of the insect involved; the faster the developmental rate, the more critical the timing. Harcourt (1969a) also said that with intensive studies to

provide a complete generation life table, regular sampling throughout i.e timing and frequency of sampling are very important in assessing rates of mortality from natural enemy, effect of competition and other factors. Varley and Gradwell (1970) considered that if there were a choice between extensive and intensive studies, intensive study in one place would be of prime importance, as it would more accurately describe the functional relationships.

5.3 Key factor analysis.

Key factor analysis is a standard term for methods for analyzing data on the total numbers entering stages for a series of successive generations of a stage structured populations (Manly,1988). Key factor analysis (Varley and Gradwell 1960,1968) is one of the many techniques used to assess the importance of various mortality sources and intervals to total generation mortality and this technique is known to detect density dependent, delayed density dependent and density independent mortalities.

Morris (1959,1963) proposed that in an animal population, there are key influences which largely determine generation mortality. He introduced the concept of key factor analysis that aimed to determine those factors that were of the greatest importance in predicting future population trends. Although Morris (1959, 1963), recognised that there was a distinction between density dependence and delayed density dependence, he did not say that his method of key factor analysis could separate the two; rather, he claimed that his method could only separate between density-dependent and density-independent mortality (Nielson and Morris 1964). On the other hand, Varley and Gradwell (1968) claimed that their method could detect direct, delayed and inverse density dependence in addition to density independence.

Subsequent studies by Southwood (1967), Hassell and Huffaker (1969), Luck (1971) and others have shown that there were many difficulties in the interpretation of the census data or results when Neilson and Morris' (1964) method was used and that Varley and Gradwell's (1968) method was to be preferred. Many field studies have not detected density-dependent processes (Dempster and Pollard 1986; Morrisson and Strong 1980; Stiling 1987). This led many of the workers to conclude that population densities are determined by density independent mortality factors (Strong 1986).

Hassell (1985,1986) reported that previous life table studies may have been inadequate because of their failure to recognize variation of prey densities through space. He said that pest populations in many situations are patchy,partly due to the spatial variation in host plants and natural enemies may be responding in a density dependent manner to these localied densities and that by averaging across an area, one may miss this density dependence, as done in most life table studies. Hassell (1985) described the need to collect life table data from a sampling design that is stratified both in space and time.

Apart from weather and natural enemies which might act as key factors in population regulation in insect species, the availability of food may act directly as a key factor in certain insect populations. Dempster (1971) found that the positive growth of populations of cinnabar moth, *Tyria jacobaeae* (L.) was limited by the availability of the host plant. Madsen *et al.* (1963) reported that decline in pear psylla in orchards was due to the poor condition of the orchard trees. White (1978) proposed that the single most important factor limiting the abundance of most animals was a relative shortage of nitrogenous food for young, growing individuals. This view was developed from a study of the outbreak of *C. densitexta* in 1969 from which White (1969) concluded that the physiological stress of trees resulting from water logging increased the amount of nitrogenous food available in the foliage to *C. densitexta,* increasing the chances of survival and reproduction. White (1973, 1974 and 1976) took an extreme position by correlating high plant stress with outbreaks of a number of phytophagous insects. Marshall (1959) attributed hot, dry weather as the key factor in the mortalities of free-moving fourth and fifth nymphal instars of *P. pyricola;* and the solidification of the droplets of honey dew, within which the first, second and third nymphal instars feed, as the key mortality factor for those stages. Clark (1962,1963a,b,c,d,1964a,b,c) in his study of the biology and population dynamics of *C. albitextura* on *Eucalyptus blakelyi* (Maiden) reported that the population density of *C.albitextura* was determined by the quantity and quality of food plant,intraspecific competition, predators, parasitoids and weather. However Watmough (1968) reported that emigration together with the factors outlined by Clark (1962, 1963 and 1964) determined the numbers of broom psyllids.

5.4 Computing methods

The application of computing methods to insect population dynamics has provided new techniques for estimating and analysing mortalities and/or survivorship of stages in insect populations (Richards 1940; Richard and Waloff 1954, 1961; Manly 1974 a,b,1988; Ruesink 1975; Birley 1977,Varley and Gradwell 1960, 1968, Liebhold and Elkinton 1988; Hassell 1985,1986) and other workers. Richards' (1940) method, which gives a valuable indication of nymphal mortality in a series of random or systematic samples in which the number of each instar found corresponds with the time spent in that instar, has been successfully used by Watmough (1968a) to estimate the nymphal mortalities of *A. spartiophila* and *A. genistae* on broom. The essential condition for this method that the food plant occurs in a homogenous area of sufficient size that the removal of substantial samples for examination does not affect the attractiveness of the area for oviposition. The Varley and Gradwell (1960, 1963 a,b, 1965 and 1968 key factor method is also a convenient way of analysing data; this method demands data from a series of successive life tables. In this key factor method, the whole generation is considered, making it immediately apparent in which age/stage interval the density development and key factors lie. Varley and Gradwell's (1968) key factor method allows recognition of the key factors or the time at which these factors act. The role of mortality factors at every stage in the life cycle is considered in this method and, more importantly, the recognition of different density relationships between these factors and an indication of their mode of operation. Subsequent studies by Southwood (1967), Luck (1971), Hassell and Huffaker (1969) and others have found that Varley and Gradwell's (1960) method is preferrable to that of Morris' (1963) key factor analysis.

6. The reaction of psyllids to materials secreted by aphids

Kislow and Edwards (1972) reported that several species of aphids and other insects were repelled by the odour of droplets released by the cornicles of other aphids. The repellant odour secreted by the aphid acts as an alarm pheromone and, in most instances, its chemical identity is (E)-ß-farnesene (Bowers *et al.* 1972; Edwards*et al.* 1973; Wientjens *et al.* 1973; Pickett and Griffiths, 1980). Bowers *et al* .(1972)

Table 2

Occurrence and biological activity of aphid alarm pheromone

Sources of tested material (droplets, extracts,etc) or tested compound	*Myzus persicae*	*Amphorophora agathonica*	*Chaetosiphon fragaefolii*	*Tuberolachnus salignus*	*Acyrthosiphon pisum*	*Brevicoryne brassicae*	*Rhopalosiphon padi*	*Metopolophium dirhodum*	*Macrosiphum avenae*	*Myzus persicae*	Biological activity to synthetic farnesene	Presence of -β-farnesene
Myzus persicae	+	+	+	-	+	-	-	-	-	-	-	-
Amphorophora agathonica	+	+	+	-	+	-	-	-	-	-	-	-
Chaetosiphon fragaefolii	+	+	+	+	+	-	-	-	-	-	-	-
Tuberolachnus salignus	-	-	-	-	-	-	-	-	-	-	-	-
Acyrthosiphon pisum	+	-	-	-	+	-	-	-	-	-	-	-
Brevicoryne brassicae	-	+	-	-	-	-	+	+	+	+	+	+
Rhopalosiphon padi	-	-	-	-	-	-	+	+	+	+	+	+
Metopolophium dirhodum	-	-	-	-	-	-	+	+	+	+	+	+
Macrosiphum avenae	-	-	-	-	-	-	+	+	+	+	+	+
Myzus persicae	-	-	-	-	-	-	-	-	-	-	+	+
Macrosiphum rosae	-	-	-	-	-	-	-	-	-	-	+	+
Acyrthosiphon pisum	-	-	-	-	-	-	-	-	-	-	+	+
Schizaphis graminum	-	-	-	-	-	-	-	-	-	-	+	+
Aphis gossypii	-	-	-	-	-	-	-	-	-	-	+	+
Macrosiphum euphorbiae	-	-	-	-	-	-	-	-	-	-	+	-
Macrosiphum avenae	-	-	-	-	-	-	-	-	-	-	+	-
Acyrthosiphon solani	-	-	-	-	-	-	-	-	-	-	+	-
Myzus persicae	-	-	-	-	-	-	-	-	-	-	+	-
Rhopalosiphum maidis	-	-	-	-	-	-	-	-	-	-	+	-
Rhopalosiphum padi	-	-	-	-	-	-	-	-	-	-	-	-

(from Wientjens et al(1973)

2. Developmental biology of Psylloidea

The development of every insect involves three major stages namely the embryo, the immature instars and the adult. Embryonic development occurs within the egg which is well supplied with yolk and surrounded by a delicate outer shell or chorion. Following hatching or eclosion, the insect feeds and grows, moulting several times until the adult reproductive stage is reached.

All psyllids pass through an egg and five nymphal instars before becoming adult. Bhattacharya (1972) and Walton (1960) reported that psyllids are strictly bisexual, with the male the heterogametic sex. An exception is *Psylla myrtilli* (Wagn.) which is claimed to be parthenogenetic (Lauterer, 1963). The external sex organs appear post-embryonically and develop continuously throughout the nymphal stages (Zucht 1972). By the fifth instar both male and female nymphs are morphologically distinct (Hodkinson 1973a; Ball and Jensen 1966; Ossiannilsson 1970). Burts and Fischer (1967), working on pear psylla, reported that in adult females, maturation of eggs may occur quickly and oviposition can commence within five days of emergence. However, females which hibernated probably delayed egg development until spring. Takara *et al.* (1986) reported a pre-oviposition period from 1 - 3 days for *Heteropsylla cubana* (Crawford), a psyllid attacking *Leucaena leucocephala* (Lam.) in Hawaii.

2.1 Life Cycle features of Psylloidea

Atwal *et al.* (1970) and Pande (1972) reported that under tropical conditions, generations are continuous throughout the year, but the growth rates are governed by prevailing climatic factors and the condition of the host plant. Psyllids have evolved mechanisms to survive the winter period when the host plant is dormant and they are recorded as overwintering in all life stages in north temperate and arctic regions (Vondracek, 1957). Overwintering diapausing eggs are usually laid on the dormant buds of the host plant by *Psylla mali* (Schmidt.) while overwintering nymphs inhabit favourable microclimates on the host plant such as beneath bud scales (by *P. ambigua* Forst.), in leaf axils (by *Strophingia* sp.) or on the underground stolon rosettes of perennial plants (by *Craspedolepta* sp.). Two basic forms, summer and winter, have

been identified in *Psylla pyri* (L.) (Kharizanov, 1969). In *P. pyri*, adults enter diapause to overwinter on the host plant. Diapause is induced by low temperature/short photoperiod (Thanh-Xuan 1972b) and the resulting forms are morphologically distinct from adults produced in summer (Bonnemaison and Missionnier 1955, 1956). Wong and Madsen (1967) and Oldfield (1970) investigated the influence of photoperiod and temperature on diapause in *P. pyricola* (Forster) in California. The conditions they used to produce summer and winter forms were a 16-hour photoperiod at 25°C and a 11-hour photoperiod at 17°C respectively. The summer forms were generally of lighter colour and winter forms darker and larger. These two forms, according to Wong and Madsen (1967), differed biologically as well as morphologically. The summer female was able to oviposit within a week after adult emergence whereas the overwintering female had an ovarian reproductive diapause. In British Columbia, Wilde and Watson (1963) reported that low temperatures were required for termination of diapause in *P. pyricola*. They also reported a definite ovarian diapause in overwintering females.

The development of two forms in *P. pyri* was shown to be directly dependent on photoperiod and the reproductive diapause in *P. pyri* was induced by exposing fifth nymphal instars and adults to a short photoperiod (Bonnemaison and Missionnier 1955). It was also found that a 12-hour photoperiod produced the longest diapause which was further lengthened by exposure to high temperatures. Low temperatures decreased the length of diapause and nutrition apparently had no effect on its termination. An aestival-autumnal-hibernal reproductive dormancy as an adult has been reported for *Euphyllura phillyreae* (Forst.), a psyllid which infests olive trees in Greece (Prophetou-Athanasiadou and Tzanakakis 1986). Hoffmann *et al.* (1975) noted that *Acizzia rusellae* (Forst.) nymphs in summer are much lighter in colour than winter forms. They presumed that this was meant to minimize heat uptake from the sun. Very few species of psyllid overwinter as adults on their host plant; most disperse onto shelter plants, particularly conifers, and move back onto their true host plant to mate and oviposit in the spring, usually prior to bud burst (Schaefer 1949). No knowledge of the biology and ecology of *C.thysanura* has been reported to date.

2.2 Biology of the immature stages

2.2.1 Egg

There is extensive literature on the water relations of insect eggs (Edney 1957; Hartley 1965), but relatively little attention has been paid to those eggs which are inserted into plant tissues and less still, psyllid eggs. Psyllid eggs all possess a basal pedicel which is inserted into the host plant tissue. Water is taken up from the plant through the pedicel and eggs quickly desiccate if the water source is removed (White 1968a). Van der Merwe (1923) and Clark (1962) recorded that eggs collapse and do not hatch if the tissue on which they are laid dries out. Some authors, Wilcke (1941) and White (1968a), maintain that psyllid eggs possibly derive nutrients as well as water from the host tissues. Wilcke (1941), although not advancing any evidence to support the hypothesis, considered that the work done on water absorption by insect eggs does not eliminate the possibility that dissolved materials may also be taken up. Eggs of *H. cubana* are deposited on new terminal growth and are attached by a stalk inserted into the leaf surface, through which fluids are taken up from the host plant, since removal of the egg causes it to shrivel within a day (Takara *et al.* 1986). Catling (1971) reported that physiological changes in leaf tissue may affect the mechanism of water absorption. Eggs can be laid superficially on a leaf or bud surface (*Paratrioza cockerelli* Sulc.), be deeply embedded in the plant tissue (*Arytaiana spartii* Guer.) or laid in leaf axils (*Strophingia ericae* Curt.). Eggs laid in protected situations suffer less predation than those laid superficially (Watmough 1968a).

2.2.2 Nymph

Many data suggest that psyllid nymphs are highly susceptible to desiccation, particularly at high temperatures, and that this is an important factor contributing to population control (Atwal *et al* 1970; Catling and Annecke 1968; Green and Catling 1971). Not surprisingly, nymphs are most susceptible to desiccation at the moult when the ability to retain water is reduced (Hodkinson 1973b: Pletsch 1947). Marshall (1959) reported that hot, dry weather is injurious to the psyllid, *P. pyricola*; however, the most vulnerable ones were the freely moving fourth and fifth instar nymphs which were killed, presumbly by desiccation, but nymphs in the earlier stages died as a result

of the solidification of honeydew within which they fed.

Moreau and Robert (1985) emphasised that cold weather alone seldom causes heavy mortality of indigenous pests owing to such adaptive behaviour as diapause, although it may kill species newly introduced to a climatic region to which they are not yet well adapted. It was also found that the differential effects of cold weather on pests and their parasitoids could cause a temporary increase in pest populations. However, repeated cold spells alternating with mild ones during which overwintering insects resume activity can cause severe mortality, for example, to cereal aphids and some psyllids. Van der Merwe (1941) also noted high mortalities among nymphs of *Trioza erytreae* (Del Guercio) during hot summer days in Durban while in cooler weather the insects thrived

An inverse relationship established between temperature and psyllid populations has been reported by List (1939); Madsen *et al.* (1963); Clark (1964); Moran and Blowers (1967); and Catling (1969).

Catling (1969), based on *in situ* counts of *T. erytreae* colonies on citrus in the field, concluded that a saturation deficit of 26mm Hg was critical for the survival of this species, but the direct effect of temperature on the insect, especially the nymphal instars, and the role of the host plant remained unresolved. In the case of *A. russellae,* Hoffmann *et al.* (1975), reported that it was likely that direct short term temperature effects were responsible for a fall in psyllid population numbers. Furthermore, very effective cooling of the host plant, *A. karroo,* ensured that the leaf temperatures of the host plant did not exceed ambient air temperatures even in strong sunlight, so that *A. russellae* nymphs showed no symptoms of temperature stress on the host plant even at temperatures of 35°C in strong sunlight and made no attempt to seek shelter in the shade under the leaves. Seemingly, *A. russellae* and the host plant are admirably adapted to withstand higher summer temperatures.

Evaporative cooling by plants (Heinckel 1964; Collier *et al.* 1973) and by insects (Mellanby 1932; Gunn 1942; Farnworth 1972; and Wigglesworth 1972) is a well known phenomenon, but few attempts have been made to relate these effects to survival of sapsucking homopterans at critically high temperatures in the field or laboratory. Broadbent and Hollings (1951) determined the influence of heat on five species of

aphids, after short exposures of sixty minutes and showed that survival of the aphids was greater on the host plant. It was concluded that aphids presumably can cool themselves by evaporation when feeding. Furthermore temperatures on the surfaces of the transpiring leaves are lower than that of the air and these lower temperatures will aid survival. In addition, the dorsoventral flattening of nymphs gives them a high surface area to volume ratio and hence a high potential for water loss. However, psyllid nymphs have evolved various mechanisms by which water loss is reduced.

In *Cardiaspina densitexta* (Taylor) hatching of first instar nymphs is controlled by a combination of light/dark periodicity and early morning temperature; nymphs emerge just after dawn and thus have time to settle and begin feeding before they are exposed to the effects of high temperature/low humidity (White 1968b).

In some Australian species of the family Spondyliaspidae, North American *Euphalerus* sp. and in one *Pachypsylla* sp., the nymph forms an enveloping protective lerp or nest from the honeydew (or wax?) which it produces (Miyatake 1968; Russell 1971; White 1971). Certain species e.g., *Trioza fletcheri* (Crawford) live in the mesophyll tissue of the host plant (Bindra and Varma 1969) while other species live in the humidity-buffered environment of a roll leaf gall (Thanh-Xuan 1970). Those species living in protected situations such as leaf axils e.g., *Aphaleura floccosa* (Patch), produce a lot of flocculent wax threads (Patch, 1909) while in some tropical, free living forms, such as *Swezeyana* sp., the nymph is completely covered in a characteristic meshwork of wax filaments (Tuthill 1966).

Madsen *et al* .(1963) noted that the absence of new growth and the poor condition of the foliage caused a steady decline of pear psylla numbers in abandoned orchards in California. This would not be a factor in commercial orchards where proper cultural practices are used, but may be a limiting influence on the survival of pear psylla in abandoned pear trees.

2.3 Adult biology

2.3.1 Dispersal

Johnson (1969) reported that dispersal of insects by flight forms an integral part of their population dynamics. When dispersal by flight of the insects is related to density,

suggested that this compound could also be used to provide a novel method of control by dispersing aphids from their feeding sites. However, Kislow and Edwards (1972) again reported that the function of the repellant odour was to (a) prevent the influx of other species to the aphid feeding site, (b) cause intra-specific spacing of the aphids on the resource, (c) induce emigration of aphids to new growths, (d) repel predators from individual aphids, (e) cause other aphids to disperse when an individual aphid is attacked by a predator, and (f) excrete metabolic wastes or toxic plant compounds. Calabrese and Sorensen (1978) said that aphids dispersed by their alarm pheromone mostly recolonised the plant surfaces within an hour of exposure. An unsuccessful approach was made by Hille Ris Lamber and Schepers (1978) who used a slow release formulation of (E)-ß-farnesene to restrict virus spread by aphids in potatoes. Montgomery and Nault (1978) also discussed the possibilities of using alarm pheromones to protect crops from aphid-transmitted viruses. A third suggestion by Edwards *et al.* (1973) was that an alarm pheromone might enhance the effectiveness of insecticidal sprays by increasing aphid activity and thereby increase contact with the toxicant. Increased contact with pesticides could enhance the contribution that contact action makes to the effectiveness of systemic sprays or make the use of contact poison more effective. Such an approach could now be more valuable for aphids developing resistance to insecticides (Hardy 1975; Sawicki and Rice 1978). No work has so far been done on the effect of either the repellant odour or the presence of aphids on psyllids, although Kislow and Edwards (1972) said that one of the functions of the repellant odour was to prevent the influx of other species to the aphid feeding sites. Bowers *et al.* (1972) identified trans-ß-farnesene as the alarm pheromone of *Macrosiphum rosae* (L.), *Acyrthosiphon pisum* (Harris), *Schizaphis graminum* (Rondani) and *Aphis gossypii* (Glover).

Nault *et al* .(1973) described the secretion and perception of the alarm pheromone (E)-ß-farnesene, by four aphid species. Montgomery and Nault (1977) investigated the response of fourteen species of aphids to the alarm pheromone (E)-ß-farnesene and found great general repellancy. They also found that the responses of apterous and alate morphs of *M. persicae* as well as that of young and old individuals were not the same (Montgomery and Nault, 1978). Pickett and Griffiths (1980) obtained positive

results by combining (E)-ß-farnesene and a contact insecticide under laboratory conditions. They also found three isomers of farnesene in the cornicular exudate of *M. persicae.*

Farnesene, including the isomers excreted by aphids, is synthesized by many plants and animals. (E) -ß-farnesene has been found in hop leaves (Naya and Kotake 1971), in *S. berthaultii* (Gibson and Pickett 1983) and in the waxy layers which cover some apple species (Murray 1969). However, aphids do not derive these compounds from their host plant. All aphids contain symbionts, which are transferred by the mother to the young and to the oviparae via the eggs. These symbionts, in addition to playing a role in the biosynthesis of steroids, may also be involved in that of farnesene production (Cane 1979).

7. Control of Psyllids

Although control of aphids has received much attention within recent years, literature dealing with the biology and control of the closely related psyllids is limited and scattered over a wide range of journals. As psyllids are pests of economic importance of cultivated crops and ornamental trees and are vectors of many plant diseases, their control is of considerable importance. Chemical control measures are generally used against psyllids, although sometimes, such control is not applied specifically to psyllids, but against other insects of greater economic importance to the grower. Thus target insects and non-target psyllids are controlled at the same time. O'Neill (1949) reported the control of pear psylla, *P. pyricola*, using parathion spray which was directed to control other pear pests, but was found during assessment to also control *P. pyricola.*

Morgan and Downing (1950) reported that an early summer spray of parathion readily controlled *P. pyricola* in most orchards. However, it was found that wherever parathion had been used in British Columbia, most beneficial insects had been completely destroyed. Missonier (1952), in his work on the control of *P. pyri,* stressed the importance of timing in the application of control measures of psyllids. The use of parathion in summer was discouraged as natural enemies were then susceptible. There was no comment on the effect of parathion on natural enemies at the

bud-burst stage of apples. Moreton and Bryden (1957) combined low volume insecticide application with correct timing of sprays in their work to control the oat apple aphid, *Rhopalosiphum insertum* (Wlk.) and the green apple aphid, *A. pomi.* These measures also controlled the non-targeted *P. mali* on the apples. Studies to control *Typhlocyba tennerrima* (H-S), *I. rosae* and *Macropsis fuscula* (Zett) on loganberry were reported by Raine and Tonks (1960). They found that the application of trithion in mid-May in addition to one of malathion, diazinon, sevin, methoxychlor and azinphosmethyl controlled *M. fuscula;* only phorate, endrin, mevinphos and demeton controlled the first generation of *T. tennerrima* and *T. rosae*; and dimethoate drench was applied to loganberry crowns in April to control *T. tennerrima* and *T. rosae* nymphs.

Morgan (1984) reported that field applications of either Malathion 0.4% a.i., Imidan 0.4% a.i. or Bidrin 85% a.i. was effective in controlling *C.densitexta* on pink gum in South Australia.

The use of so many chemicals reflects the paucity of knowledge of the biology of the pests being controlled. It was, therefore, not a surprise when Jensen *et al.* (1961) reported that the grape leaf hopper, *E. variabilis,* had developed resistance to DDT, malathion and sevin in vineyards in California. The standard for satisfactory control in field tests is at least 98 per cent reduction in numbers of nymphs and, on this basis, neither trithion nor sevin was satisfactory in California. These chemicals were effective in sprays and dusts in May and in dusts alone later, but it was pointed out that because of the severe resistance problems of pests, the performance of insecticides was unpredictable. There was also a report of resistance development by *P. pyricola* and fruit tree mites to organophosphates so that mixtures of chlorinated hydrocarbons were being used against these pests (Kiigemagi and Terriere 1963).

With the development of resistance attention was turned to other forms of control. Jaques and Patterson (1962) noted that *P. mali* adults were attacked and killed by the fungus, *E. sphaerosperma,* although nymphs were rarely killed. They found that sulphur and, to a lesser extent Bordeaux mixture, repelled or killed the psyllid so the use of these fungicides was recommended between 1930-1950. However, when these inorganic fungicides were replaced by organic fungicides, *P. mali* subsequently

increased in numbers between 1955-1959.

When *P. pyricola* developed resistance to malathion and diazinon, Madsen and Westigard (1963) reported that control could still be achieved by sprays of other organophosphates. They found that oil emulsion sprays alone or with pyrethrins gave good initial control, but a rapid increase in population density soon followed. Dimethoate (30% e.c.) successfully controlled jarrah leaf miner in *E. rudis* and *E. marginata* (Wallace 1966). Although not directed against psyllids, it was found to effectively control psyllids attacking *E. rudis*. Carden (1987) resorted to a schedule of "treat when necessary with insecticides" to control apple pests. He reported good control of *P. mali* and greater savings in the supervised spray programme compared with the regular spray programme. Atger and Lemoine (1984) introduced pruning of pear orchards to control *P. pyri*, concluding that the degree of pruning, together with pear variety, determined the level of infestation by *P. pyri*. Following the discovery of resistance in *P. pyri* to some organophosphate insecticides, Staubli and Antonin (1984) directed research towards the development of programmes that considered pest biology, natural enemies, the effect of pesticides on the natural enemies and the general mode of action and timing of applications of the different chemicals. They recommended that broad spectrum contact chemicals not be used in summer to control summer fruit tortrix moth, *Cydia pomonella* (L.) because anthocorids, which prey on pear psylla, were colonising the orchards at that time.

McMullen and Jong (1971) also reported that pear psylla had developed resistance to a wide range of chemicals over 20 years in the Pacific North-West. In British Columbia, the insecticides that were recommended for pear psylla control and to which resistance had developed included benzene hexachloride, parathion, malathion, diazinon, carbaryl, dieldrin and azinphosmethyl. Undoubtedly,the failure of many other related insecticides for pear psylla control could be attributed to cross resistance. Since psyllids, like aphids, are of economic importance and have developed resistance to a wide range of insecticides, there is the necessity to develop integrated pest management programmes against them.

7.1 What is integrated pest management.

Integrated pest management (IPM) as a concept is not new, only the name is. Watson *et al.* (1975) reported that many of the components of a sound integrated pest management programme were known some fifty years through Dwight Isley's research in the mid -1920's. Isley's extensive work on cotton insects and mites in 1924 provided a sound basis for IPM today. His work was based on the principles of applied ecology. Watson *et al.* (1975) defined IPM as the practical manipulation of insect or mite populations using all control methods in a sound ecological manner, but integrated control according to Watson *et al.* (1975) is the integration of the chemical and biological control methods. Integrated control is a term which is frequently encountered and often used interchangeably with IPM, though in the real sense these terms are not identical. Integrated control was originally coined by Bartlett (1956) to define the blending of biological control with chemical control.

Rabb (1972) described pest management as the intelligent selection and use of pest control actions that ensures favourable economic, ecological,and sociological consequences. Bottrell (1979) described IPM as a concept of pest control composed of many components, all of which taken together provide the resources and knowledge which are necessary for the provision of ecologically sound pest management systems that consider the whole cropping system. He said that IPM is also a decision making process to determine if, when, where, and what strategy or tactics to use in pest management programme. Smith (1980) reported that IPM systems should be flexible and offer a variety of options because of the changing pest problems, control technologies, economics and human values. The integrated approach to insect control has been reviewed by many workers: Ripper (1958), Smith and Hagen (1959), Wood (1972), Metcalf (1974), Bottrell (1979), Smith (1980) and Mitchell (1984). Geier (1966) pointed out that the development of pest management for a particular pest is not the mere imposition of control techniques, but should be based on the ecology of the ecosystem involved. Watson *et al.*(1975) reported that the basic elements of a sound IPM system are the utilization of natural control, the use of sound economic levels and and the understanding of the biology and ecology of the pest and also all the species present in the ecosystem.

Huffaker (1972) reported that a pest management programme depends on the resources to be protected, economic values, availability of personnel etc and the understanding of the pest complex. Mitchell (1984) also reported a number of assumptions that must be accepted in an IPM programme which are (i) IPM rejects the belief that the mere presence of a pest species should justify action for control and that IPM is a containment strategy not an eradication strategy, (ii) no single control measure will do the job for a complex of pests, (iii) the farmer or producer should accept certain level of damage or loss, (iv) IPM does not discriminate against the use of pesticides as a control measure, but it reduces the sole dependence upon pesticides for pest control, (v) IPM utilizes all the control factors to work together, and (vi) IPM does not work for all pest problems. The application of a pest management system, therefore, depends on an understanding of the agro-ecosystem and the population dynamics of the pests and other organisms within it (Wood 1972). The acceptance or recognition of the ecosystem concept and its complexity is important in understanding the IPM system (Van den Bosch and Stern 1962).

Chant (1964) reported that pest management is particularly suitable for occasional pests which at most times are under natural or biological control, but become a pest when changes in the agro-ecosystem occur and their population increases to economic levels. He called these types of pests,"class II pests". He also categorised as class III pests those potential pests which did not cause significant damage at their current level until there were changes in their agro-ecosystem and, for these pests, an integrated approach could be developed which could ensure that the pests did not change their status.

To develop an ideal pest management system for these key pests, Wood (1972) said that the system should be based on the study of the pest's population dynamics and full use made of life table and key factor studies so that suitable control methods which had minimal disturbance on the agro-ecosystem could be chosen.

The use of the pest's life table concept has also been described by Le Roux (1963) as the key to a practical understanding of pest problems in the agro-ecosystem and the intelligent use of control factors. Metcalf (1974) also reported that the use of the pest's life table showing the key factors affecting it provides valuable information required in

planning the most effective insecticide intervention, timing and integration with other key factors. The key factor studies enabled the key mortality factor of the pest in question to be determined and those factors utilised in the integrated control system.

7.2 The integration of chemical control with natural enemies

Van den Bosch and Stern (1962) reported that both chemical control and the action of natural enemies or biological control are involved in the reduction of pest numbers, but are in no way similar phenomena. The integration of chemical control and the action of natural enemies is, historically, the most important technique in a pest management system (Wood 1972). Stern *et al.* (1959) reported that biological control governs the population density of a pest species and forms part of natural control, but chemical control, according to Metcalf (1974), results in rapid and high mortality of the pest population, usually within hours of its application. In general, chemical control is used when natural enemies or other control measures fail to prevent economic damage from occurring and this is usually done to avoid maximum destruction of the natural enemies and this together with other control measures are utilized to achieve sound ecological pest management system. To achieve this objective, Metcalf (1974) reported that selective use of pesticides should be adopted.

Smith and Hagen (1959), Painter (1951), Van den Bosch and Stern (1962), Wood (1972) and Metcalf (1974) all reported the non-availability of selective chemicals for a given arthropod species and most materials in use today are broad spectrum pesticides. However, in an ecosystem where parasitoids and predators are abundant or effective, any chemical application which would shift the balance back in favour of natural enemies would be ideal and could be incorporated in an IPM programme (Stern *et al.* 1959). Selectivity of chemicals could be achieved in several possible ways. Ripper (1956) broke selectivity down into physiological and ecological selectivity, while Metcalf (1974) broke it down to physiological, ecological and behavioural selectivity and selectivity through improved application of the pesticides.

Physiological selectivity of pesticides is very difficult to achieve; however, ecological selectivity occurs where the timing or placement of the chemical material reduces its overall disturbance of the ecosystem. This could be done in a number of

ways. Adkisson (1971) reported that ecological selectivity could be achieved by the replacement of preventive routine treatment schedules with "treat when necessary" schedules and also a more selective means of insecticide application based on sound knowledge of the pest ecology. Smith and Allen (1954) also achieved ecological selectivity of chemicals in their supervised control of alfalfa caterpillar in California by treating those areas where the pest to natural enemy ratio was unfavourable.

Anonymous (1965) report showed that about 50-75 per cent of sprayed or dusted insecticides do not hit the target organism: they either fall to the ground or drift away from the treated area. Another way of increasing selectivity in chemicals is by lowering the dosages of toxic chemicals. According to Wood (1972), this reduces the period during which the host plant retains residues harmful to beneficial insects. Ripper (1956) demonstrated the effect of reduced dosages of schradan in cabbage aphid control. The principle of reduced dosages of pesticides had also been used successfully in control programmes for several forage and field crop pests in California (Stern, 1961). Stern and Van den Bosch (1959) and Adkisson (1971) also showed that disulfoton used against green bug, *Schizaphis graminum* (Rondani), in Texas, was fully as effective at 0.1 lb per acre as at 0.25 lb per acre, and parathion at 0.1 lb per acre gave control almost as effective as that at the recommended dosage of 0.5 lb per acre.

Madsen and Williams (1968) obtained nearly as effective control at one-half the dosage (2.5 lb per acre) and reasonably good control at one-quarter the dosage (1.25 lb per acre) when they used azinphosmethyl against the coddling moth, *C. pomonella* (L). Batiste (1972) also reported differences in the control of *P. pyricola* when azinphosmethyl was used at 4 oz and 2 oz a.i. per 100 gallon, respectively, in integrated control of *C..pomonella* in California.

Smith *et al.* (1985) reported that chlorpyrifos at dosage rates as low as 0.14 kg (a.i.) /ha suppressed green bug, *Schizaphis graminum* (Rondani) and conserved natural enemies. They also reported that green bug control at 0.14 kg (a.i.)/ha was equal to that obtained at the labelled dosage rate of 0.5 kg (a.i.)/ha. Selectivity could also be achieved through proper use of non-persistent, rapidly degradable insecticides such as nicotine, tetraethyl pyrophosphate, mevinphos and trichlophon if applications

were properly timed to coincide with periods when beneficial insects were in protected places or untreated reservoirs or were in forms that could survive initial applications of the chemical (Van den Bosch and Stern, 1962).

Bartlett (1958) and Stern and Van den Bosch (1959) all demonstrated that parasitoids of the spotted alfalfa aphid, *Therioaphis maculata* (Buckton), survived non-selective chemical treatments if they were in the pupal (mummy) stage. It was also found by Stern and Van den Bosch (1959) that mevinphos, a non-persistent organophosphate, had advantages over parathion and malathion in the control of spotted alfalfa aphid because it produced no mortality in parasitoids emerging from mummified aphids or coccinellid larvae hatching from eggs.

Stern and Van den Bosch (1959) also reported that systemic insecticides usually showed pronounced selectivity against plant-sucking bugs such as aphids, psyllids, mites and thrips and, sometimes, chewing insects. These authors advised that demeton at a low dosage of 2.0 oz per acre could control spotted alfalfa aphid without any detrimental effect on the natural enemies and so was therefore suitable for an integrated control programme for this pest. It is evident from the above review that there are practical and effective ways of integrating chemical and biological control measures, but their development into an IPM programme is limited by many factors which have been extensively reviewed by Van den Bosch and Stern (1962) , Wood (1972), Metcalf (1974), Bottrell (1979), Smith (1980) and Mitchell (1984).

Traditional control of psyllids was, in general limited and, in the case of *C.thysanura* , consisted of regular spraying throughout the year by the boronia growers. Therefore in the development of an IPM programme for *C.thysanura* a number of questions were posed and answered in the context of the knowledge of the behaviour and life system of the pest.

CHAPTER 2

MASS REARING TECHNIQUE FOR *C.thysanura*

1. **INTRODUCTION**: The effects of infestations of *B. megastigma* have resulted in a need for basic biological and behavioural studies including aspects of the insect host plant interaction, the role of exotic and indigenous natural enemies as well as studies determining appropriate methods of control. Such studies necessitated an abundant, reliable and consistent supply of insects. Mass rearing of the psyllid in the laboratory should be capable of providing known quantities of insects of uniform age and bionomic background to facilitate these and other studies.

The aim of this work was to develop a mass rearing technique that would provide large numbers of *C.thysanura* on demand.

2. **MATERIALS AND METHODS**.

The mass rearing trials were conducted in a glasshouse illuminated by a 40W "Osram" one metre flourescent tube attached to the ridge and a thermostatically controlled fan heater and an air conditioner.The flourescent tube was controlled by a time clock which permitted a controlled period 12:12 hr light-dark(12L:12D). Access to the glasshouse was through a sliding glass door which was kept closed after entering and leaving the glasshouse to avoid extreme temperature fluctuations. The air temperature ranged from 18-20°C with a relative humidity of 65-75 per cent measured by a 7-day recording thermohygrograph.Three different methods of rearing *C. thysanura* were compared.

C. thysanura adults were collected from foliage of naturally infested field grown boronia at farms at Copping and Kingston using a sweeping net on September 10,1986. The collected psyllids were anaesthedized with ether, sexed and the culture established with pairs of males and females.

2.1 Rearing method No.1:

Twenty cut boronia shoots, 15-20 cm long, were confined in glass vials 75x15mm containing water and two pairs of psyllids placed on each of the cut shoots.

The cut shoots were taken from 6 months old HC4 clonal material developed at the Horticultural Research Centre,University of Tasmania.This cultivar has a history of higher psyllid infestations than on other cultivars. The cut shoots were placed in a cage of 53x45x48 cm. Five psyllid infested cut shoots were placed in one cage and, in all, four cages were established.

2.2 Rearing method No.2

This trial was established on September 22, 1986. In this trial, ten 6-month old potted HC4 clonal boronia plants were infested with two pairs of adult psyllids and the potted plants kept in cages as in"Rearing method No.1".

2.3 Rearing method No.3

Twenty potted seedlings of 6 month old HC4 variety 10-20 cm long were infested with psyllid adults as in the other two trials.

Each infested plant was placed in a cage manufactured from 2 L plastic soft drink containers 30 cm long and a diameter of 15 cm(Fig.2).

The plastic bottle cages were inverted and the seedling plant inserted through the mouth into the bottle space. The plastic cages were held in place over each plant by means of rubber bands from two long sticks inserted into the soil on either side of individual bottles. Ventilation was obtained through two opposite 10 x 10 cm holes made at mid height of the cage. Each hole was covered with fine nylon cloth held in place by means of cellotapes. The open end of the plastic bottle cage was also inserted into the soil of the potted plant so that the whole plant was enclosed giving no access for spiders or other natural enemies. The psyllids on the plants could be observed from outside the bottles so that there was no need to disturb the system prior to actual counting.

The height of the "plastic cage" could be altered as the infested plant grew by moving the plastic bottle up and supporting it with longer sticks on the sides. As the

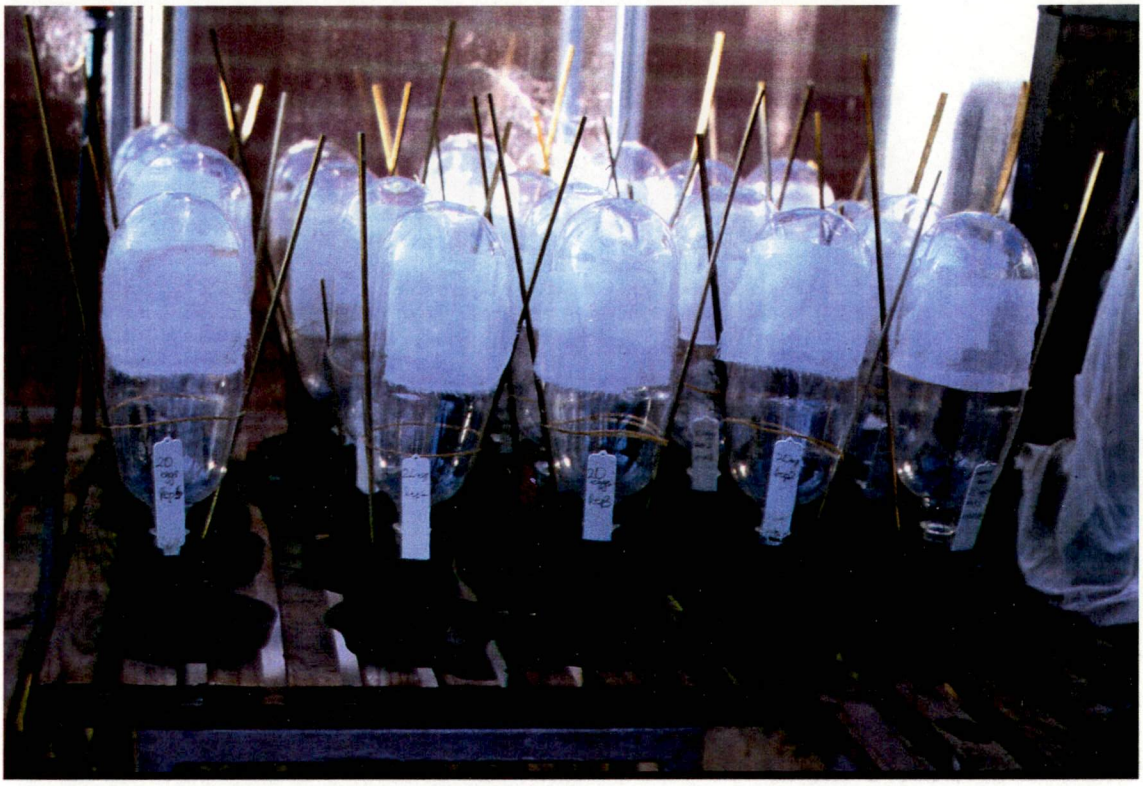


Fig.2
Plastic bottle cages used for rearing C.thysanura in the laboratory.

basal opening was lifted from the soil, cotton gauze was inserted at the end to prevent entry or escape of insects.

3. Results.

3.1 Rearing method No.1

This rearing method for *C. thysanura* was unsuccessful for the terminal shoots of the boronia plants commenced to wilt after 10 days even though the shoots were immersed in water. This necessitated frequent replacement of shoots which was labour intensive and disruptive to culturing.

In addition, within 10 days the eggs laid by the female psyllids had not hatched and could not be transferred to the new terminal shoots. Most of the adult psyllids were lost in the process of transfering them to the new shoots. No adult psyllids emerged from this culture.

3.2 Rearing method No.2

It was observed that the potted plants maintained their turgidity but the psyllids were attacked by spiders. Spiders entered the cages and built webs around the growing tips of the psyllid infested plants and actively preyed on nymphal and adult psyllids and this led to the termination of the trial.

No psyllid nymphs developed through to adult in this method.

3.3 Rearing method No.3

This method proved to be ideal because in addition to the potted plants maintaining turgidity and health throughout the development of the insects, it also excluded spiders and other natural enemies and unwanted insects such scales and aphids which often interfer with glasshouse cultures.

The first batch of adults emerged 41 days after infestation.

4. Discussion:

The pest status achieved by *C. thysanura* on boronia necessitates studies of the biology and behaviour of this insect. Studies on *C. thysanura* required a ready source

of experimental material. A number of cage designs have previously been employed for psyllid culture eg. cut twigs immersed in glass vials (Van der Merwe 1941), cellulose acetate cylinder cages (Watmough 1968), perforated plastic bags (Annecke and Cilliers, 1963 and Moran and Blowers 1967), and organdie bags (Clark 1962).

The advantages of using ventilated plastic cages on potted plants are they avoid the wilting associated with cut stems, (Van der Merwe 1941) and Moran and Blowers (1967) and exclude natural enemies and other unwanted insects such as spiders, scales, aphids etc (Watmough 1968). It provided a more constant enviroment and optimal conditions for both plant and insect growth and permitted direct observation of the insects through the wall of the plastic cages without disturbance. It also overcame the problem of excessive prolonged instar development encountered by Van der Merwe (1941) and Moran and Blowers (1967).

The only problem in the method with respect to mass rearing was that the potted seedling had to be replaced as the population of the insect increased, which due to intraspecific competition for food and space reduced the efficiency of output. When insects were subcultured to new plants on regular basis, this technique provided a consistent insect population for laboratory studies.

Chapter 3

The biology of *C. thysanura* on its host, *Boronia megastigma* (Nees)

1. Introduction

While the biologies of other psyllid species have been studied (Watmough 1968 a,b; Clark 1962, 1963; Pletsch 1947; Burts and Fisher 1967; Rasmy and Macphee 1970; Hodkinson 1973 b; and others), there is no information on the biology and ecology of *C. thysanura.* To obtain detailed biological information as a basis for ecological studies and sound pest control practices, *C. thysanura* was studied extensively on boronia plants in both glasshouse and field trials.

This section describes the insect's life stages, rates of egg and nymphal development and ovipositional patterns on the host, *B. megastigma.* The spatial distribution of psyllid eggs in relation to the position of nodes on the host plant's terminal shoot was determined. In addition, the longevity of both sexes of *C. thysanura,* sex ratio, mating behaviour, egg fertility and the rates and amounts of oviposition by individual females are also described. A field study was conducted to establish whether *C. thysanura* was attracted to colour in order to gain a better understanding of the nature of the stimuli to which the insect responds. Such information is necessary for the development of a more efficient trapping technique for estimating the incidence of *C. thysanura* adults and its flight phenology.

2. Materials and Methods

Unless otherwise stated, plants of the HC4 cultivar developed at the Horticultural Research Centre, University of Tasmania, were used in these studies. The glasshouse in which the studies were conducted was maintained at 18 -20^{o}C with a relative humidity of 65-75% as described previously in Chapter 2.

2.1 Life cycle of *C. thysanura* and the description of stages

The life cycle of the psyllid was studied using 140 potted boronia plants which were 6 months old and of the same approximate height. The plants were conditioned in the glasshouse for 48 hours and then each plant infested with two mated 6 day old adult *C. thysanura* females selected from a culture maintained in the same glasshouse where the experiment was being conducted. The plants were infested on 21 November 1986. Each infested plant was enclosed in a plastic bottle cage. A pair of mated female psyllids was allowed to oviposit on a plant for 24 hours, after which they were removed. Next, the leaf axil of each infested plant was examined for the presence of eggs under a binocular microscope; following location, all but two eggs were destroyed. Leaving two eggs on each plant enabled the duration of each stage to be examined critically, since the eggs and five nymphal instar can only be seen under the microscope. The incubation period was determined by daily examination of five different plants. After examination, the condition of that stage was recorded and the five plants were set aside from the unexamined plants. This method was continued until the nymphs reached the second instar, after which plants were examined daily through the plastic bottle cage using a hand lens (10x). The reason for separating plants examined under the microscope was that any disturbance of the plant during assessment might prolong the instar duration (Moran and Blowers 1967).

Records were taken of the time the nymphs appeared in eggs and the incubation period (taken from the end of the exposure period of the plant to psyllids until the eggs hatched). The lengths of 20 eggs, both with and without the pedicel, were measured with a binocular microscope fitted with a micrometer eye piece. The duration of each of the five nymphal instars was determined by noting when each moulted. The number of antennal segments, the length and width of the head capsule between and including the eyes of 20 individuals of each instar were recorded. The widths of the head capsules (between and including eyes) of 20 newly emerged male and female adults were also recorded. Twenty adult females which were 48 hours old were dissected in a glass petri dish containing water and the numbers of ovarioles were recorded. Adult weights of 20 newly emerged males and females were measured on a microbalance ("Sartorius, model 4125"). General observations of the activity and

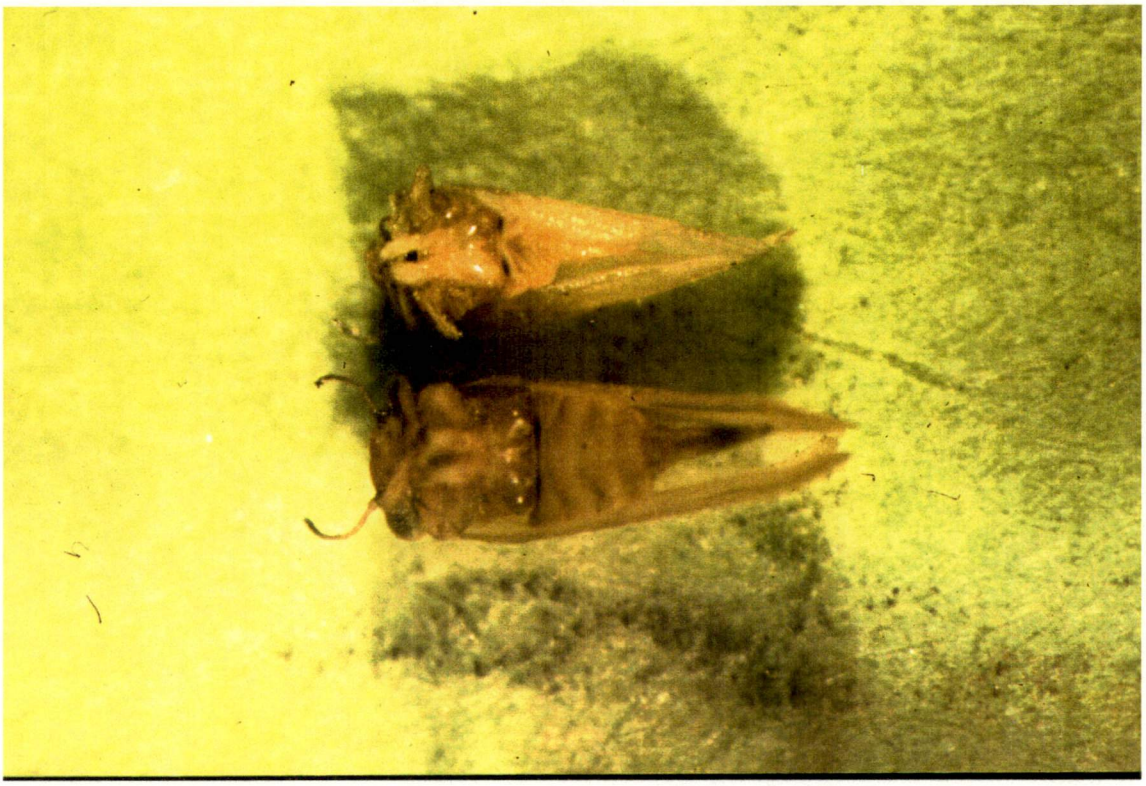


Fig.3
C.thysanura adults. Top: male; Bottom: female (x 3)

behaviour of each stage were made.

2.2 Adult longevity and female fecundity

Adult longevity and female fecundity were obtained by isolating newly emerged pairs of 2 males and 2 females on 6 month old potted HC4 boronia plants enclosed in plastic bottle cages. Each pair was transferred to a new, potted boronia plant every 5 days and the eggs laid within that period on the exposed plant were recorded. When a male died during the study, it was replaced to ensure mating. The time at which each adult insect died was also recorded. The experiment was replicated 10 times, thus 20 pairs of insects were studied. The change to new ovipositional sites was continued until all test insects had died.

2.3 Egg deposition pattern of *C. thysanura* females in relation to the position of leaf nodes on host plants

This experiment was commenced on 30 January 1987 using 10 month old potted HC4 boronia plants (10 in number) exposed to 10 pairs of male and female psyllids in a large cage (53x45x48 cm) for 10 days, i.e., just before the eggs began to hatch. The eggs laid in each leaf axil, numbered 1, 2, 3, 4, 5, etc. from the tip of the terminal shoot, i.e., the youngest to the oldest leaf axil, were counted under a binocular microscope. One terminal shoot was left on each plant; the rest were destroyed. To compare the egg oviposition patterns of female psyllids in the field with those in the glasshouse, 10 randomly selected terminal shoots, 15cm long, were collected from Kingston and the number of eggs in each leaf axil counted.

2.4 The attractiveness of previously infested boronia plants for oviposition

In this study, previously infested boronia plants from which adult psyllids had emerged were taken from the mass rearing trials and kept free from re-infestation for 7, 14 and 21 days, respectively. These plants, together with a plant that had not been previously infested, as a control, were exposed to 25 mated 6 day old female psyllids in the large cage. The insects were removed after 10 days. This experiment was

Fig.4

C. thysanura egg batch within a leaf axil of a boronia plant. (x 10)

replicated 5 times in different large cages in the glasshouse. After 10 days, the numbers of eggs on each plant were counted and recorded.

2.5 The attractiveness of newly developed side shoots of previously infested boronia plants for oviposition

For this study, a previously infested potted boronia plant from the mass rearing trial, which had been kept free of psyllid re-infestation for 21 days and, as a consequence, had developed new side shoots together with the original terminal shoot, was used to determine whether female psyllids prefer the newly developed side shoots to the original terminal shoot. The side shoots of the plants, which had three nodes excluding the tip of the bud, were pruned and only one side shoot was left on each plant. Each plant was enclosed in a plastic bottle cage and infested with two 6 day old, mated female psyllids which were left to oviposit for 10 days. The experiment was replicated 5 times. After 10 days, the eggs on the leaf axils of the new shoots and the original terminal bud were counted and recorded separately.

2.6 Mating behaviour and the mating preference of the male psyllid

To determine if the male psyllid is the aggressor in mating and whether male psyllids prefer unmated virgin females to mated ones, a newly emerged 24 hour old female was caged on an enclosed potted boronia plant with a 10 day old female psyllid which had developed charcteristic black stripes on the abdomen (an indication of old age). A 10 day old male was then introduced into the plastic bottle containing the differently aged females and the behaviour of the male and its preference toward the two females were observed.

Records were also taken of the time mating took place and the duration of a single mating.

2.7 The effect of mating on egg fertility

Pairs of newly emerged male and female psyllid adults were placed on 6 month old potted boronia plants enclosed in plastic cages. A second series consisting of a single

newly emerged female only was established. Each treatment was replicated 5 times and the number of eggs laid was counted after 10 days. Records were taken of the number of eggs that hatched in order to determine the egg fertility of mated and unmated females.

2.8 Field study on colour preference of *C. thysanura*

Studies on the colour preference of *C. thysanura* were conducted using field trapping techniques similar to those used by Prokopy (1972). The traps consisted of 30x30 cm aluminium squares painted on both sides first with a white primer undercoat and then with two coats of one of the five long-life gloss enamel colours to be tested. The enamels were yellow (Y) (Dulux Aust. Ltd., Clayton, Victoria) and white (W) (Dulux Aust Ltd., Clayton, Victoria). The remaining three hues were made from a mixture of yellow (Y) and white (W) in the following proportions: 3Y : 1W; 1Y : 1W; 1Y : 3W. The reflectance characteristics of the five colours were measured by a Pye Unicam SP8 - 100 uv/visible recording spectrophotometer (Pye Unicam Ltd).

After drying, a smooth, thin layer of Bird Tanglefoot (The Tanglefoot Company, Grand Rapids, Michigan, U S A) was applied to the entire surface of each square. (Bird Tanglefoot is colourless and seemingly odourless). The traps were supported in a furrow cut in a piece pipe, 35 cm in diameter and 35 cm long. The two pipe openings were tightly covered with a square of wood the same diameter as the pipe. This left a cavity in the pipe underneath the sticky trap so that any psyllids washed away from the sticky traps during rainfall could be captured and therefore be included in the assessment together with those on the sticky traps.

This experiment was conducted in a boronia farm at Kingston, Tasmania, from 30 November 1986 to 31 August 1987. The boronia plants were 2 years old, of the same approximate height and planted in blocks. The plot was arranged in a completely randomised block design of six colour treatments with eight replications. Each replication occurred within one block of boronia plants 30 m in length with six colour traps. In all, six blocks of boronia plants were used for the experiment. The traps were set up 21 days after plants were pruned and fertilised to take advantage of the development of new shoots.

The psyllids trapped on the sticky traps were collected separately from each side every 10 days by carefully removing the psyllids with a small pin and then sexing them in the laboratory. Records were taken of male and female *C. thysanura* adults separately on each sampling occasion. After removing the psyllids from the traps, each trap was washed with kerosene, dried in the sun and recoated with the trapping adhesive before being mounted again in the field. The data were analysed by Analysis of Variance and differences in means by Duncan's Multiple Range Test ($P \leq 0.05$).

3. Results and Observations

3.1 Life cycle and description of stages

Under glasshouse conditions, egg development of *C. thysanura* ranged from 10-12 days after emergence and 95 per cent of eggs hatched on 10 to 11 days post oviposition (Table 3). Eggs were laid singly, or in batches ranging from 5 to 20, in the leaf axils of young terminal shoots of boronia plants.

Eggs were elongate and 0.270±0.002 mm long and were always attached to the stem tissue by means of an inserted pedicel 0.100±0.002 mm long (Table 4). The eggs were transparent when first laid and the nymphs could be seen in the egg within 9.04±0.12 days after laying (Table 3) and when the egg turned from cream to yellow. There were five nymphal instars and the mean duration for total nymphal development in the glasshouse (110 individual nymphs) was 40.46±0.32 days with a range of 37-44 days (Table 3). The development of the first instar nymphs required an average of 4.28±0.05 days; the second, 4.40±0.06; third, 5.00±0.12; fourth, 6.84±0.02 and the fifth instars, 8.49±0.12 days (Table 3).

Table 3

Time in days required for *C. thysanura* to develop on *B. megastigma* (HC4 cultivar) under glasshouse conditions (18-20°C and relative humidity of 65-75%).

Stage	Average duration ($\bar{X} \pm Se$)	Range
Egg (nymph formed in egg)	9.04 ± 0.12	8-10
Incubation period	11.45 ± 0.12	10-12
First instar	4.28 ± 0.05	4-5
Second "	4.40 ± 0.06	4-5
Third "	5.00 ± 0.12	5
Fourth "	6.84 ± 0.02	6-7
Fifth "	8.49 ± 0.12	8-10
Total	40.46 ± 0.32	37-44

On eclosion, the first instar remained in the leaf axil for 24 hours and then wandered for a short distance to feed briefly at different sites until day 4 when it moulted. The second instar moved from the original site to the softer new nodes just below the apex to feed. Each subsequent nymphal instar up to the final fifth increasingly moved about the plant seeking the preferred tender tissues. These preferred tissues were located at the first three nodes from the apex which were soft and tender whereas the fourth node became woody.

Tables 4 and 5 show the average body length, width of head capsule and numbers of antennal segments of the five nymphal instars. The general colour of the instars was golden yellow. They were flattened dorsoventrally, giving them a high surface area to volume ratio.

Table 4

Length (mm) of the egg and each of the five nymphal instars of *C.thysanura* (mean of 20 individuals).

Stage	Maximum	Minimum	Average X ± Se	No.of antennal segments
Egg (Including pedicel)	0.28	0.26	0.270±0.002	-
Excluding pedicel	0.18	0.16	0.170±0.002	-
First instar	0.41	0.39	0.400±0.002	3
Second "	0.62	0.58	0.600±0.004	4
Third "	0.82	0.78	0.800±0.005	5
Fourth "	1.01	0.99	1.000±0.002	7
Fifth "	1.26	1.24	1.250±0.002	8

The mean length of the first instar was 0.400±0.002mm and that of the fifth stage, 1.250±0.002 mm (Table 4). The average width of the head capsule (including eyes) of the nymphal instars were 0.150±0.003 mm for the first ; 0.250±0.004 mm (2nd); 0.320±0.003 mm (3rd); 0.380±0.003 mm (4th); and 0.450±0.003 mm for the fifth (Table 5). There was a positive correlation ($P<0.001$) between body length and (1) the width of the head capsule, (2) the number of antennal segments (Fig.5 A,B). A significant positive correlation ($P<0.001$) between number of antennal segments and head capsule width was also obtained (Fig. 5C).

The nymphal instars have short and stout antennae with the first nymphal instar having 3 antennal segments and subsequent stages 4, 5, 7 and 8 (Table 4). The adults of *C. thysanura* generally have a yellowish-brown colour with darker markings. Black transverse bands develop on the ventral surface of mature females which are more than 10 days old. Immature females less than 10 days old have no such markings on the abdomen.

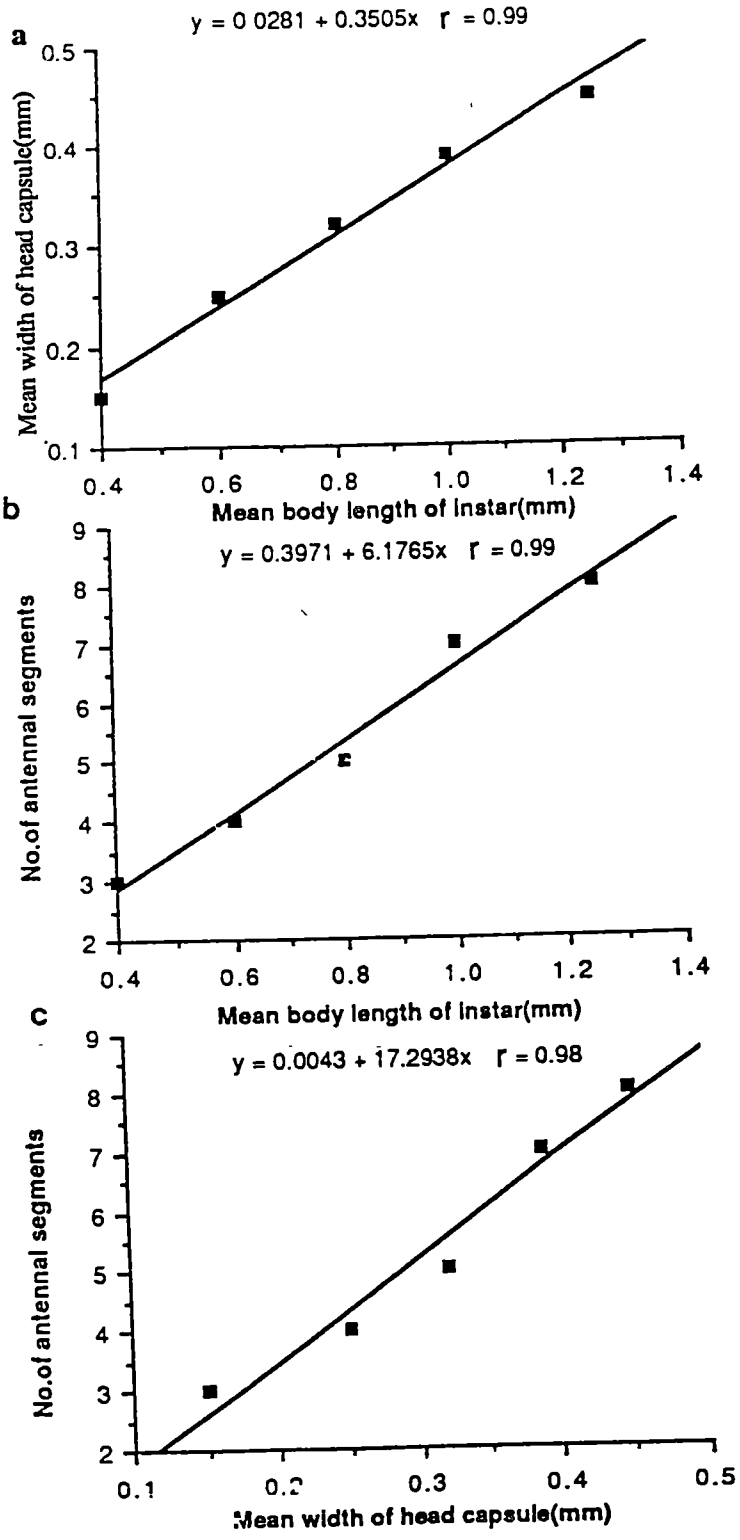


Fig.5

Relationship between the (a) head capsule width; (b) body length; and (c) number of antennal segments of *C.thysanura* nymphal instars in the glasshouse.

Table 5

Head capsule width (mm) of *C.thysanura* nymphal stages under glasshouse conditions. (mean of 20 individuals).

Instar	Maximum	Minimum	Average
First (Between eyes)	0.11	0.11	0.11
(Including eyes)	0.15	0.15	0.15
Second (Between eyes)	0.18	0.18	0.18
(Including eyes)	0.25	0.25	0.25
Third (Between eyes)	0.23	0.21	0.22
(Including eyes)	0.33	0.31	0.32
Fourth (Between eyes)	0.30	0.26	0.28
(Including eyes)	0.40	0.36	0.38
Fifth (Between eyes)	0.36	0.34	0.35
(Including eyes)	0.46	0.44	0.45

The wings of the adults were yellowish. The antennae of the adult were slightly shorter than the width of the head capsule. The genitalia of the female was very long and slender and the dorsal plate beset along the apical half of its ventral margin. In the male, the genitalia was distinctive with the proctiger having a slender apical lobe.

The adult females weighed 0.110±0.003 mg and the males 0.070±0.002 mg (Table 6). The head capsule width of the male was 0.407±0.006mm and that of the

female was 0.489±0.003 mm (Table 4). There was no significant difference in the size and weight of cultured and field collected psyllid females nor in their ovariole counts ($P<0.05$). The number of ovarioles of the laboratory reared female was 53.500±0.235 and that of the field collected was 53.200±0.268 (Table 7).

Table 6

Head capsule width (mm) and live weights of *C. thysanura* adults under glasshouse conditions. (mean of 20 individuals).

Sex	Mean width of head capsule (mm) X ± Se	Mean live weight (mg) X ± Se
Male	0.407 ± 0.006	0.070 ± 0.002 a
Female	0.489 ± 0.003	0.110 ± 0.003 b

Table 7

Number of ovarioles of laboratory reared and field collected *C. thysanura* females. (Mean of 20 individuals).

	Mean no. of ovarioles (X + Se)
Laboratory reared	53.500 ± 0.235 a
Field collected	53.200 ± 0.268 a

Lsd (0.05) =0.819; Lsd (0.01) =1.120

Means followed by the same letter are not significantly different ($P>0.05$), Duncans multiple range test.

3.2 Sex ratio and adult longevity

The sex ratio of *C. thysanura* is 1.1 : 1.0 males to females under glasshouse conditions; and of the 110 adults that emerged in the life cycle experiments, 58 were males and 52 were females (Table 8). The difference in the number of each sex was not significantly different ($P_{X^2} > 0.05$) indicating a sex ratio of 1 : 1 (Table 8).

Table 8

Sex ratio of *C. thysanura* reared on HC4 boronia plants under glasshouse conditions. (n=110).

Sex	No. of emerging adults	Sex ratio Male:Female
Male	58 a	1.1:1.0
Female	55 a	
Total	110	

Chi-square analysis

Treatments	Observed(O_i)	Expected(E_i)	O_i-E_i	$(O_i-E_i)^2$	$\frac{(Oi-Ei)^2}{E_i}$
Male	58	55	3	9	0.1636
Female	52	55	-3	9	0.1636
Total	110	110	0	18	X^2=0.3272

P X^2=>0.05 NS

Adult longevity and female fecundity studied in the glasshouse showed an average life span for mating ovipositing females of 25.20±1.99 days; males, 15.30±1.02 days with the difference of 9.90 days being significantly different ($P<0.05$). The range was 12-33 and 11-23 days for males and females, respectively (Table 9).

Table 9

The longevity of *C. thysanura* adults after emergence in the glasshouse. (mean of 20 males and females).

Treatment	Mean ($X \pm Se$)	Range
Male	15.30 ± 1.02 a	11-23
Female	25.20 ± 1.99 b	12-33
Total	40.50	11-33

Means followed by the same letter are not significantly different ($P>0.05$), Duncan's multiple range test.

Analysis of variance

Source of variance	Degrees of freedom	Sum of squares	Mean square variance	F
Treatments	1	980.1	980.1	59.5139**
Blocks	19	586.5	30.8684	1.8744
Error	19	312.9	16.4684	
Total	39	1879.5	1027.4368	

Lsd(0.05)=2.67 days; Lsd(0.01)=3.67 days

3.3 Mating behaviour, mating preference, female fecundity and egg fertility

It was observed in the study that males were the aggressors in mating. The males became active from time to time and sought out females. These periods of activity increased markedly as mating frequency increased. In all this time, the females usually stayed at one spot apparently feeding for hours but not displaying the same restless activity as the male. Only rarely did females refuse the advance of males and mating commenced when the male inserted its aedeagus and both male and female faced opposite directions. When the insects were disturbed during mating, the female usually pulled the male in her direction and could even jump with the male still connected and this attachment remained until copulation was eventually terminated. The duration of mating was usually less than two minutes when disturbed, increasing to more than 30-40 minutes if left undisturbed. Mating was more frequent in the afternoon and late evening.

The number of eggs laid per female during the first 5 days after emergence was 2.55, then this increased to 36.80 for days 6-10 (Table 10). Oviposition after 10 days declined to 0.15 eggs per female in 26-33 days after emergence (Table 10). During this time the female was aged and nearing death. The female psyllid deposited an average of 85.55 eggs within its lifetime (Table 10).

In the experiment to determine preference of a male psyllid to two female psyllids of different ages, the male psyllids continuually mated with the virgin females without making any advances towards the mature females. Mated females produced a mean number of 43.00 eggs, of which 42.00 (98 per cent) hatched, whereas none of the 6.00 eggs laid by the unmated females hatched (Table 11).

Table 10

The number of eggs laid by *C. thysanura* on boronia plants under glasshouse conditions (18-20°C and relative humidity of 65-75%). (mean of 20 females).

Days after emergence	No.of eggs/female
1 -5	2.55 a
6-10	36.80 b
11-15	23.75 c
16-20	16.30 d
21-25	6.00 e
26-33	0.15 a
Total	85.55

Lsd(0.05)=3.63; Lsd(0.01)=4.77

Table 11

The oviposition and egg fertility of mated and unmated *C. thysanura* females on boronia plants after 10 days under the glasshouse conditions.(mean of 5 replicates)

Treatments	Mean no.of eggs/female	Mean no.of eggs that hatched (% hatchability)
Mated female	43.00 a	42.00 a (98.8)
Unmated female	6.00 b	0 b (0)
Total	49.00	42.00

Means within column followed by the same letter are not significantly different (P>0.01), Duncan's multiple range test

Mean no.of eggs/female [Lsd(0.05)=7.65;Lsd(0.01)=12.69]

Mean no.of eggs that hatched [Lsd(0.05=6.33;Lsd(0.01)=10.50]

3.4 Egg deposition pattern of *C. thysanura* in relation to the position of the leaf node on the host plant

The female psyllid preferred to oviposit in the terminal shoots of boronia plants. However, the highest number of eggs were laid in the leaf axils of the third and fourth nodes under both glasshouse and field conditions (Table 12).

Table 12

C. thysanura egg deposition pattern in relation to the position of the leaf node on the host plant under glasshouse and field conditions. (mean of 10 replicates in the glasshouse; and 10 randomly collected terminal shoots of HC4 boronia cultivar from the field).

Position of leaf on the terminal shoot	Mean no.of eggs/leaf axil	
	Glasshouse	Field
Tip of terminal shoot(terminal bud)	1.20 a	0 a
Leaf node "1" from terminal bud	4.20 a	1.20 a
Leaf node "2" " " "	9.90 b	4.50 ab
" " 3 " "	22.80 c	10.60 c
" " 4 " "	25.70 c	8.80 c
" " 5 " "	13.00 b	5.30 b
" " 6 " "	5.10 a	1.20 a
" " 7 " "	3.00 a	0 a
" " 8 (ie basal leaf node)	0.20 a	0 a
Total	85.10	31.60

Means within column followed by the same letter are not significantly different (P>0.01), Duncan's multiple range test.

Glasshouse [Lsd(0.05)=4.87;Lsd(0.01)=6.40

Field [Lsd(0.05)=3.51;Lsd(0.01)=4.62

The number of eggs laid in the leaf axils of the nodes decreased from 25.70 to 0.20 for the soft fourth to the eighth, mature node, respectively (Table 12). In the field, eggs were only rarely found in the leaf axils of nodes 7 and 8 (Table 12). The female psyllid refused to lay at the tip of the terminal shoot in the field, but in the glasshouse, an average of 1.20 eggs were laid (Table 12). Equal numbers of eggs (P>0.05) were laid in the third and fourth nodes under both glasshouse and field conditions (Table 12).

3.5 The attractiveness of previously infested boronia plants for oviposition by female psyllids

Previously infested plants became attractive to female psyllids 21 days after adults had emerged from these plants (Table 13).

Table 13

The attractiveness for oviposition by *C.thysanura* on previously infested boronia plants with severely damaged shoots kept from outside reinfestation. (Mean of 5 replicates).

Days after adult emergence from the previously infested plant	Mean no.of eggs/plant	Range
7	1.60a	1-5
14	30.80b	20-44
21	60.00c	40-80
Control(Previously uninfested plant)	121.00d	104-146

Means followed by the same letter are not significantly different,(P>0.05) Duncan's multiple range test.

Lsd(0.05)=17.71; Lsd(0.01)=24.83

The numbers of eggs laid per female per plant, 7, 14 and 21 days after adults had emerged from those plants were 1.60,30.80 and 60.00, respectively (Table13).

Psyllid females preferred to lay on uninfested plants (Table 13) although eggs were laid on a previously infested plant if no alternative oviposition site was available. In the latter instance, the number of eggs laid were few until approximately 21 days post infestation when plants became attractive again. The mean number of eggs laid on the uninfested plants was 121.00 compared with 1.60, 30.80 and 60.00 eggs per plant laid on previously infested plants kept from reinfestation for 7, 14 and 21 days, respectively (Table 13).

3.6 The attractiveness of newly developed side shoots of previously infested plants

The number of eggs laid per shoot on a newly developed side shoot of a previously infested plant was 106.40 which was significantly greater ($P<0.01$) compared with 35.00 in the leaf axils of the originally infested terminal shoot, a threefold difference (Table 14).

Table 14

The attractiveness of the newly developed side shoots of previously infested plants kept from reinfestation by *C. thysanura* adults for 21 days after adults have emerged from the plants. (mean of 5 replicates).

Treatments	Mean no.of eggs/shoot	Range
Leaf axils of newly developed side shoots of previously infested plant	106.40a	51-175
Leaf axils of original terminal shoots of previously infested plant	35.00b	10-50

Lsd(0.05)= 59.91; Lsd(0.01)= 99.36.

Means followed by the same letter are not significantly different,$P>0.05$, Duncan's multiple range test.

The range was 51-175 eggs for the newly developed side shoots and 10-50 eggs in the original shoots (Table 14).

3.7 Colour preference of *C. thysanura*

After 10 days, full yellow (Y) traps caught significantly more psyllids ($P< 0.05$) than any of the other hues tested, with the exception of 3Y : 1W coloured trap which was not significantly different ($P>0.05$) (Fig. 6). However, the full yellow traps consistently caught the greatest number during each test period (Fig. 7). The 3Y : 1W was next in preference with only small numbers caught on 1Y : 1W, 1Y : 3W, and least on full white (Fig. 6 and Fig. 7). The number of psyllids caught after 10 days on 1Y : 1W, 1Y : 3W and full white did not differ significantly ($P>0.05$) (Fig. 6b). The average number of trap catches in the trials declined as the colour changed from the yellow part of the spectrum to white (Figs. 2-4). On average, the full yellow trap caught 47.8 per cent of all males and 50.5 per cent of all females captured and an average 49.1 per cent of the total catch, followed by 3Y : 1W (35.5 per cent), 1Y : 1W (10.2 per cent), 1Y : 3W (3.4 per cent) and full white (1.8 per cent). The overall mean number of males to females caught by all five different coloured traps was 1.1 : 1.0 with no significant difference ($P>0.05$) between the sexes, irrespective of colour. This sex ratio did not differ from the emergence ratio, indicating no preference for colour by sex.

The highest number of psyllids were caught in May (autumn) (Fig. 7). The reflectance spectra of the painted surfaces are given in Fig. 6a. Although scanned from 400 to 760 nm, maximum reflectance occurred only between 440-480 nm. There was a positive correlation between psyllid catch and the proportion of light reflected ($P<0.001$) (Fig. 8).

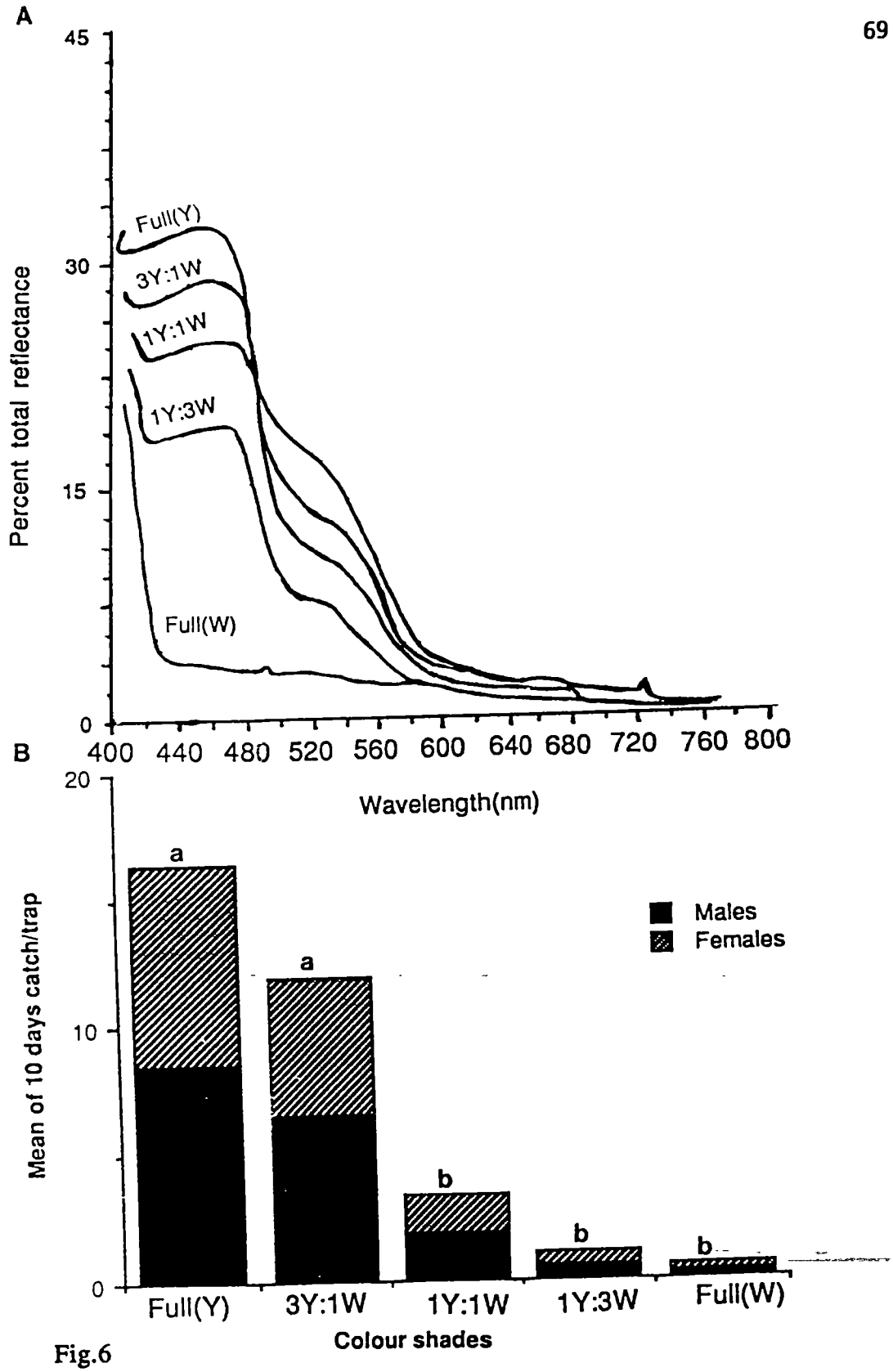


Fig.6

Spectral reflectance curves of colour enamels and shades (A), and their corresponding attractiveness to *C.thysanura* in the field (B), during the period Nov.1986-Aug.1987. (Means with the same letter are not significantly different at $P<0.05$; Duncans multiple range test). Y = yellow; W = white; and Y:W= a mixture of yellow and white colour enamels.

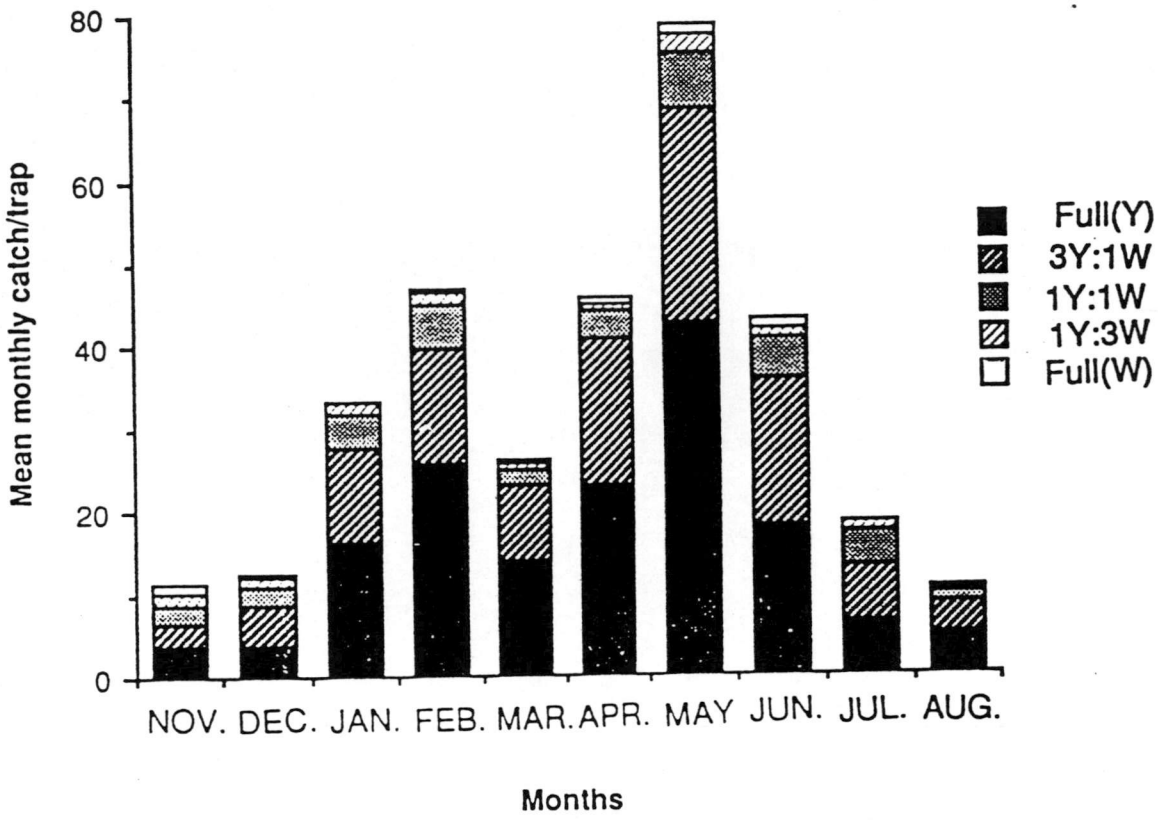


Fig.7

Mean monthly catch of *C.thysanura* (males and females) by test colours in the field.

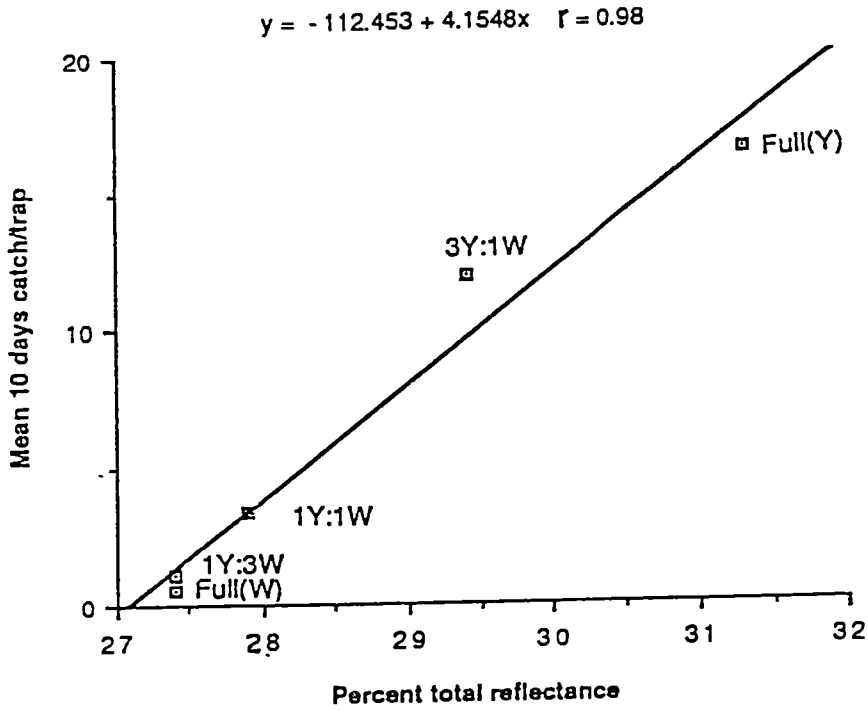


Fig.8

Relationship between the proportion of energy emitted in the 440-480nm region by test colours and the mean 10 day catch of *C.thysanura* in the field during the period Nov.1986-Aug. 1987.

4. Discussion

4.1 Life history

C. thysanura passes through an egg and five nymphal instars before becoming an adult. The egg fertility of mated females approached 100 per cent and in the life cycle trials, 95 per cent of the eggs hatched 10-12 days after oviposition. This result agrees with the findings of Burts and Fischer (1967) who reported that the egg fertility of fully mated males of *P. pyricola* approached 100 per cent during the egg laying period. *C. thysanura* females prefer laying their eggs in the leaf axils of the new terminal shoots for at least two reasons. First, as uptake of water via the pedicel is essential for egg viability, host tissues must allow penetration by the ovipositor for insertion of the pedicel (Blowers and Moran 1967; White 1968; Takara *et al.* 1986). Secondly, because nymphs of *C. thysanura* cannot live on mature or woody stems (especially the first nymphal instar which is less active and can only wander for a short distance after eclosion), survival is dependent on selection by the female psyllid of the softest and youngest node which will not reach maturity before the first stage nymph moults. The numbers of eggs deposited in batches within leaf axils in the laboratory was greater than in the field. This tendency appeared to be related to the restricted choice of favourable oviposition sites. In the glasshouse, psyllids laid on the tip of the terminal shoot down to the eighth node. In contrast, psyllid field behaviour results in eggs only in the leaf axils of the second to the sixth nodes (Table 12). Lack of sufficient oviposition sites when one terminal shoot was exposed to two females might have forced the psyllids to lay larger egg batches from the tip of the terminal shoot to the more woody seventh and eigth nodes. Clark (1963b) found that the eggs of *C. albitextura* are laid in batches on leaves of eucalypt trees and that the presence of eggs could have attracted other females to lay eggs at that site. No such attraction was observed in this work.

The reason for the first nymphal stage remaining in the leaf axil after eclosion was to enable the body to harden after which it wandered for a short distance to feed intermittently at different sites. The probable reason for the intermittent feeding was

that the original leaf axil during this period was 12 days older than at oviposition and had become harder. Since the first nymphal instar was less active, it could not leave the original site and move to the more preferred softer nodes which had been formed and so it attempted to feed at different sites until it moulted after 4 days to the second nymphal stage. The second and subsequent nymphal instars were increasingly more active and dispersed throughout the plant to exploit it. A nymph of *C. thysanura* has a high surface to volume ratio and hence a high potential for water loss. The effect of desiccation, therefore, could be severe in the field and particularly for first instar nymphs unless the nymphs obtained some degree of protection from the host plant. The susceptibility of *S. ericae* and *P. cockerelli* nymphs to desiccation, especially during moulting, has been reported by Pletsch (1947) and Hodkinson (1974).

The two parameters most often used to identify nymphal instars of psyllids are the width of the head capsule and the number of antennal segments (Taylor, K. L. pers. comm.). However, for practical purposes, the body length was used to identify *C. thysanura* nymphs in the field.

The sex ratio of *C. thysanura* is 1 : 1 and this is in agreement with other psyllids like *C. albitextura* (Clark 1962); *P. cockerelli* (Pletsch 1947); *P. pyricola* (Burts and Fischer 1967); and *A. genistae* (Watmough 1968 a,b).

In *C. thysanura,* females outlived the males (Table 9). This was also reported for *H. cubana* by Takara *et al.* (1986) and Stechman *et al.* (1987). The females are also heavier (0.110±0.003 mg) than the males (0.070±0.002 mg) (Table 7). This result agrees with Clark (1962) who reported that female *C. albitextura* were heavier than the males.

Aspects of the mating behaviour of *C. thysanura* have been observed in other psyllids (Cook 1963; Burts and Fischer 1967) and, in all cases, the males were the aggressors in mating. Mating in *C. thysanura* lasts up to 30-40 minutes when not disturbed. White (1970a) and Pande (1971) have also reported that, in most psyllid species, copulation lasts no longer than about 30 minutes, although Burts and Fischer (1967) have reported copulation in *P. pyricola* lasting up to four hours. *C. thysanura* females had a pre-oviposition period of 5 days and the maximum number of eggs laid per female occurred 6-10 days after emergence, suggesting that in any experiment on

C. thysanura where heavy oviposition is required, females which are 6 days old should be used. Pre-oviposition periods of 1-3 days have been reported in *H. cubana* (Takara *et al.* 1986). The appearance of black transverse bands on the ventral surface of mature females which are more than 10 days old enabled the older less fecund females to be distinguished from those yet to lay their maximum number of eggs. This difference is important in oviposition experiments where younger females are required. No parthenogenicity was detected in *C. thysanura.* This finding conforms with those of Watmough (1968a,b) in *A. genistae;* Clark (1962) in *C. albitextura;* and Burts and Fischer (1967) in *P. pyricola.*

C. thysanura females prefer to deposit eggs in the leaf axils of the third and fourth nodes from the tip of the terminal shoot both under glasshouse and field conditions (Table 12).

The reason for this distribution pattern is apparently that the proximity and sizes of the third and fourth nodes closely accomodate the nymph and provide greater protection from wind etc. compared with the tip of the terminal bud which was tightly compacted, and smaller first and second nodes which, though soft, do not provide protection and leave the nymph exposed. The third and fourth nodes are also softer than the basal fifth, sixth, seventh and eigth nodes which have longer internodes and are more open. They also have woody stems. A similar egg distribution pattern was observed for *C. albitextura* by Clark (1963b).

C. thysanura females lay few eggs on previously infested terminal shoots (Table 13). This was caused by honeydew contamination associated with the excreta of the nymphal instars. The low numbers of eggs laid by *C. thysanura* adults on previously infested shoots kept for 7 and 14 days (Table 13) could not be explained entirely as a direct effect of food shortage. It may be that it is unsuitable for oviposition due to a wound response or residual contaminants. Female psyllids caged on severely damaged terminal shoots laid very few eggs although they survived throughout the 10 day trial on previously damaged plants without loss of vigour. After 10 days, dissections of the female psyllids caged on the severely damaged terminal shoots showed that females contained mature eggs. This suggests that egg laying was inhibited by the foliage condition.

After keeping the previously infested plants for 21 days without reinfestation, the damaged leaves were apparently restored to their original condition and new side shoots started to develop on those plants. As a consequence, female psyllids accepted it for oviposition. However, the newly developed side shoots had 3 times more eggs laid on them than the old terminal shoot which remained generally unacceptable (Table 14). Apart from the foliage condition which attracted the female psyllids to deposit their eggs on the newly developed side shoots, the food quality could also be a factor. Newly developed side shoots were greener and possibly contained more nitrogen. White (1970b) suggested that adults have a lower requirement for nitrogen than do growing nymphs so that increasing the proportion of nitrogen in the food is not critical. However, White (1970b) remarked that females which continue to develop and lay eggs over a long period would certainly require a high quality nitrogen source. Therefore, *C. thysanura* females most probably selected a high nitrogen source in the newly developed side shoots to enable them to develop and continue to lay eggs over a longer period.

4.2 Colour preference

The results demonstrate that *C. thysanura* adults are highly responsive to yellow traps. The fact that significantly more psyllids were captured on the full yellow traps than on the full white traps (Fig. 7) strongly suggests that the psyllid attraction to yellow is the result of positive attraction. The degree to which yellow was attractive is well shown in that dilution of yellow enamel with 50% white (1Y : 1W) and 75% white (1Y : 3W) to produce yellow-white hues resulted in a significant decrease in psyllid capture (Fig. 6b and Fig. 7). Dilution of the yellow enamel with 25% white (3Y : 1W) produced no significant ($P>0.05$) difference in psyllid catch suggesting that reflectance in the 440 and 480 nm range had to exceed 29 per cent of total reflectance to promote a specific response (Fig. 6 and Fig. 8). A considerable number of other insect species also have been reported to be attracted to yellow. These include *P. pyricola* (Wilde 1962; Adams and Los 1989), as well as other homopterans (Kennedy *et al.* 1961; Kring 1967). The variety of other herbivorous insects known

to respond positively to yellow include, for example, the white fly, *T. vaporariorum* (Coombe, 1981); asparagus miner, *O. simplex* (Ferro and Sychak, 1980); the fruit fly, *A. suspensa* (Greany *et al.* 1977) and others. This response has led to the speculation that yellow constitutes a super-normal foliage-type stimulus, emitting peak energy in the same bandlength of the insect-visible spectrum as foliage emits peak energy, but at greater intensity. The highest catch for all colours was in May during autumn (Fig. 7). This shows that most adults of *C. thysanura* were active in this month seeking new feeding and oviposition sites before the onset of the winter. The high catches could also be a competitive response to the peak densities of egg and nymphal stages competitively forcing adults to fly from infested plants to search for uninfested plants.

The overall mean number of males to females caught on the traps was in the ratio of 1.1:1.0, which agrees with the ratio obtained from psyllid cultures. There was no preference for colour by sex. Yellow traps have been used to monitor *P. pyricola* populations by Kaloostian and Yeomans (1944), Wilde (1962), Adams *et al.* (1983) and Adams and Los (1989) and also the flight phenology of *P. originis* (Ridgway and Mahr 1986). Therefore, yellow traps could be used to monitor *C. thysanura* adult populations and flight phenology and could be used on boronia farms to determine the onset of increasing psyllid populations and its relationship with damage and also to evaluate the effectiveness of control measures.

Chapter 4

The pest status of *C.thysanura* with reference to its host, *B.megastigma*

1. Introduction

This section investigates the feeding behaviour of *C. thysanura* and its damage to the host, *B. megastigma* , under both glasshouse and field conditions. The damage caused by *C. thysanura* was assessed in terms of the growth of the terminal shoot, i.e., the number of new nodes formed on the terminal shoot which corresponds with the number of flowers that will be produced.

The effect of psyllid feeding on flower yield under field conditions and per cent oil extracted from the flowers was also assessed. The economic status of *C. thysanura* on its host was therefore defined. An examination of the density of infestation necessary to produce economic damage was studied and this was used to define an economic injury level for *C. thysanura* infesting 12-month old plants. A clear definition of the bioeconomics of *C. thysanura* damage to its host is important since chemical control of *C. thysanura* had been, before the start of this study, used as a prophylactic treatment.

2. Materials and methods

Unless otherwise stated, all experiments were conducted in the same glasshouse used for mass rearing and biological studies. The experimental plants were HC4 clonal variety.

2.1 Feeding behaviour of *C. thysanura*

Four 12-month old potted boronia plants were each infested with individual 6 day old male and female psyllids. Four comparable and uninfested plants were established as controls. All potted plants were enclosed in plastic cages. After 10 days, the adults were removed and eggs permitted to hatch during the next 11 days.

Observations were made on the mode of feeding of both adults and nymphs. To determine which tissues provided the food supply, nymphs were killed on all four infested plants by forceps when the nymphs were beginning to moult at the fifth nymphal instar. Transverse sections of the infested terminal buds were cut and stained in 1% toluidine blue for 8 seconds and then washed with water before examination under a binocular microscope. Lignin was stained blue, cellulose pink, and feeding tracks remained unstained.

2.2 *C. thysanura* feeding and its effect on the growth and flower yield of *B. megastigma*

This experiment was conducted during the period January - July, 1987 in the glasshouse maintained at 18-20°C. Two groups of eight 12-month old potted boronia plants were enclosed in plastic cages. In one group, individual plants were infested with two pairs of 6 day old *C. thysanura*. The second group of eight plants was left uninfested. Before the infestation treatment was applied, each plant was left with five nodes from the tip of the terminal bud. The end of the fifth node on each plant in each group was marked faintly with long-life gloss enamel paint (Dulux Australia Limited, Clayton, Victoria) using a zero pin. The marked spot was only just visible when the nodes were being examined. The paint had no effect on the growth of the plant (Roberts, N. pers. comm.). Records were taken of (1) the initial number of new nodes left on the test plants for both infested and uninfested plants, and (2) at fortnightly intervals, the increase in the number of new nodes per terminal shoot. The test plants produced flower buds in May and most flowers were fully developed and had commenced to open by the end of July. Records were also taken of the number of flowers produced by each plant in the two groups. Observations were made on the effects of infestation and honeydew on the foliage in comparison with the uninfested plants.

2.3 Effect of *C. thysanura* feeding on the growth, yield and oil yield of boronia flowers in the field

The data used in the evaluation of the effect of *C. thysanura* feeding on the

number of new nodes and flowers formed per terminal shoot, the total flower yield (kg) and the per cent oil extracted from the flowers were obtained from the large scale integrated control trials conducted in 4 year old boronia plants at Copping from December,1987 - August,1988. These large scale trials were designed to assess an integrated control programme developed for *C. thysanura.*

The boronia plants used in the study had been planted in rows with spacings of 0.5 m between plants and 1 m between rows. The experimental design was a randomised block with 7 replications. The monocrotophos insecticide was applied as a foliar sprays at the rate of 0.02% a.i. using a knapsack sprayer with a cone at the end of the nozzle delivering 420 ml of toxicant per minute. The control plot was left unsprayed. The plot size for each replicate was 3 m wide and 40 m long and consisted of 60 plants. Plots were sprayed once in December, January and April.

2.3.1 Growth and flower yield assessments

The growth of the plants in each treated plot was assessed by the number of new nodes formed. In this assessment, 10 plants were randomly selected from each treated plot (one plant from replicates 1, 2, 3 and 4 and two plants from each of replicates 5, 6 and 7) and a terminal shoot from each plant was tagged on the base of the shoot and beneath the tip of the terminal bud and the first node marked with long life gloss yellow paint.

Records were taken at 28-day intervals of the number of new nodes formed and the number of psyllids both on the sprayed and unsprayed plots. The number of flowers on each tagged terminal shoot was recorded during August when all the flowers were fully open. In September, all the flowers on each treated plot were harvested both by hand and a harvesting machine and the total weights (kg) of flowers from the experimental and control plots were recorded. Again, 50 flowers from each replicate in the sprayed and unsprayed plots (a total of 350 flowers per plot) were taken separately and weighed on a Mettler PC 440 balance to compare individual flower weights. This data was used to determine whether psyllid feeding had had any effect on the individual weights of the flowers. Post-treatment assessments of both psyllids and plant growth were made at 28-day intervals.

An analytical procedure used by Judenko in 1973 to estimate the economic percentage yield loss of silage corn attacked by aphids, was employed to assess the economic yield loss of boronia flowers attacked by psyllids in the field. The results of this analytical procedure were compared with the actual percentage yield loss from the total flowers harvested from both the sprayed and unsprayed plots. The plots used for the damage experiment in the field were heavily infested with *C. thysanura* and no other pest was found to contribute to loss in yield.

2.3.2 Oil yield assessments

A sample of 150 g flowers from each of the 7 replicates of each treatment was harvested and bulked in September, 1988, for oil extraction. Each composite group sample was extracted with 700 ml petroleum ether in glass preserving jars at 40-70°C. Extraction was assisted by sonification in a water bath (30°C) for 30 minutes. Three extractions were made and each was dried on a Rotary Vacuum Evaporator (RVE) using a 30°C water bath. Records were taken of the percentage oil extracted from the flowers on a fresh weight basis. Analysis of variance was used to analyse the data for both glasshouse and field flowers and Duncan's multiple range test was used to compare the means.

2.4 Damage - density relationship tests

After preliminary observations of damage trials in the glasshouse had indicated that a high *C. thysanura* population caused noticeable damage to *B. megastigma,* additional information on the number of new nodes and flowers formed per terminal shoot was obtained in an experiment performed in 1987. This experiment was designed to determine the effects of intraspecific competition between *C. thysanura* nymphs in order to establish damage-density relationships. This information was consequently used to calculate the economic injury level for *C. thysanura* using the methods of Stone and Pedigo (1972) and Ogunlana and Pedigo (1974). The experiment was conducted from April to May, 1987 using 12-month old potted boronia plants which had developed flower buds, enclosed in plastic cages. Each of the infestation levels of 10, 20, 30, 40, 50 and 60 nymphs per plant was replicated five

times.

A second study was conducted, after the results of the first experiment were known, to determine the lowest psyllid infestation level that (a) would kill the host plant's terminal shoot, and (b) the level of infestation that could be tolerated by the host plant. This experiment involved 2 and 5 *C. thysanura* nymphs, respectively, per terminal shoot and was conducted during April-June, 1988 under 12L : 12D in the glasshouse, conditions differing from the 10L : 14D of 1987. In both experiments (1987 and 1988), infestation levels were achieved by infesting each of the enclosed potted boronia plants with two pairs of 6 day old psyllids for 3 days after which the psyllids were removed. The eggs laid were counted and, immediately after hatching, the infestation levels were adjusted by removing any extra instars with a fine camel's hair brush to establish the respective infestation levels. Counts were made of the number of new nodes formed on each plant at the different infestation levels when the first adults emerged. At the conclusion of the study at day 42 in early June, the numbers of flowers formed on each plant and the numbers of plants with dead terminal tips were recorded. Data for the number of flowers formed per terminal shoot and the number of dead shoots per plant at the different infestation levels were compared by regression analysis. Analysis of variance and Duncan's multiple range was used to test differences between mean values.

3. Results and observations

3.1 Feeding behaviour of *C. thysanura*

Examination of sections cut from infested plants revealed that *C. thysanura* nymphs formed a tubular feeding track which usually ended in the phloem, represented by the cellulosic plant tissue which stained pink. The feeding track remained unstained and was easily seen in the prepared slides, while the cellulosic portion was stained pink. It was also observed that feeding tracks usually passed through stomatal pores then passed through and destroyed several cells of the bundle sheath before ending in the phloem tissues. The feeding tracks were never observed to end in the lignified xylem tissues. There were so many feeding tracks into the phloem tissue that it was very difficult to count for most intersected with each other. Many stylet insertions at

different regions on the same stem were identified in the course of nymphal development. No feeding tracks were found in the uninfested plant slides.

3.2 Effect of psyllid feeding on the formation of new nodes

The results for the glasshouse experiments are presented in Fig. 9. They indicate that the number of new nodes formed per terminal shoot of infested plants was significantly lower ($P<0.05$) (8.61) than uninfested plants (13.19) i.e., a 35 per cent reduction. The infested plants in the glasshouse began to exhibit symptoms of reduced growth 56 days after infestation (Fig. 9). This was after the generation had ended and indicated a lag in the cumulative effect of nymphal feeding.

In the field, the infested plants produced significantly fewer ($P<0.05$) new nodes per terminal shoot (6.82) than the uninfested monocrotophos-sprayed plants (11.36) i.e., a 40 per cent reduction (Fig. 10 a). The overall mean number of psyllids at the end of the study on the infested (unsprayed plants) was 13.65 psyllids per terminal shoot compared with 2.36 psyllids on the monocrotophos sprayed plants, a 5.78 fold increase over the sprayed plants (Fig. 10 b). The difference was significant ($P<0.01$). In the field, symptoms of reduced growth commenced in January, when the mean number of psyllids per terminal shoot on the unsprayed plants was 5.00 and that of the monocrotophos-spraye plant was 0.83, but the difference was not significant ($P>0.05$) until April when the number of new nodes per terminal shoot on the unsprayed plants was significantly lower ($P<0.05$) (Fig. 10A,B); this is explained by the greater number of psyllids in March (17.33 per terminal shoot) on the unsprayed plots (Fig.10B).

It was observed that the honeydew produced by psyllid nymphs caused leaves to stick together, caused buds to rot following irrigation and encouraged extensive sooty mould. The observed symptoms shown by the infested plants included yellowing of leaves and subsequent leaf fall; stunted growth; reduced leaf number and size; and the development of compensatory side shoots which were eventually attacked and the terminal bud killed (Fig11). At the time just preceding visible symptoms of damage, the population of nymphs had developed to consist of predominantly fourth-fifth instar nymphs. In the glasshouse, mortality of all the tips of the terminal and compensatory

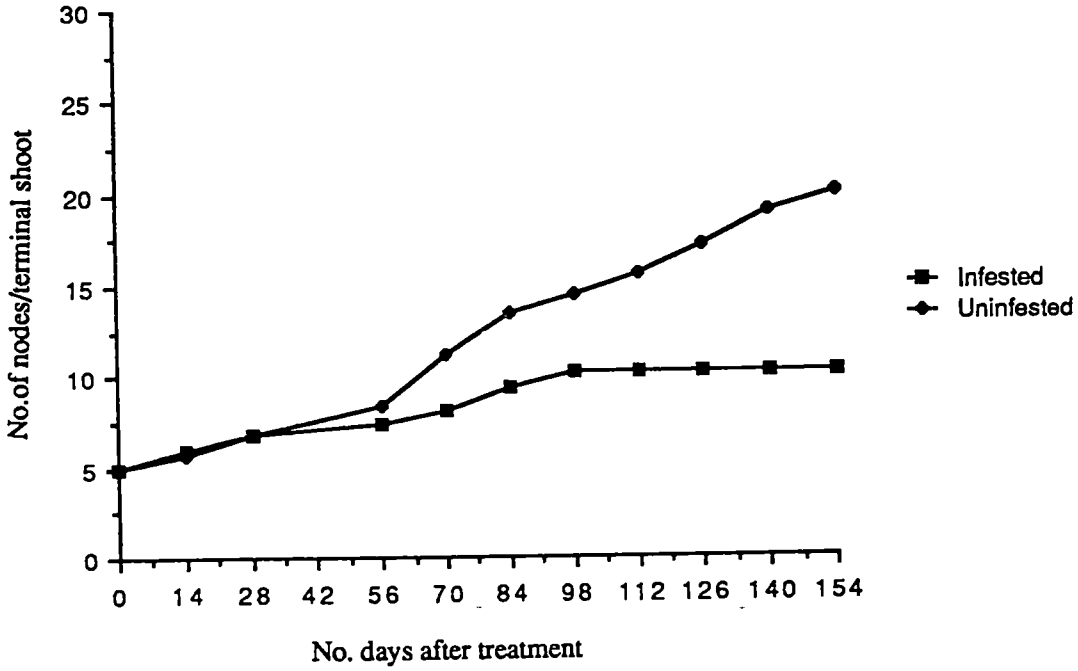


Fig.9

The effect of *C.thysanura* on the number of new nodes formed per terminal shoot relative to uninfested boronia plants.

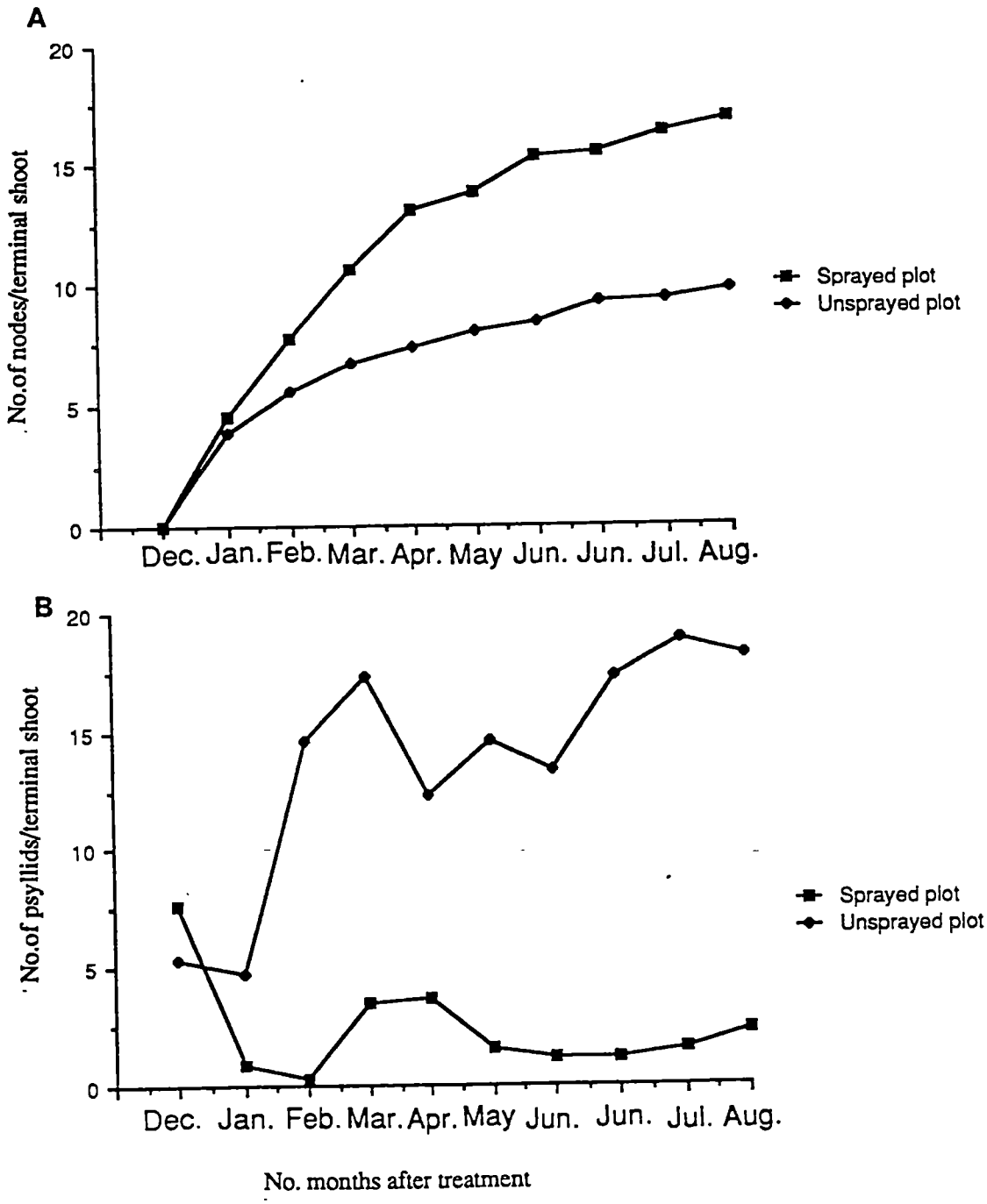


Fig.10

The effect of insecticide sprays on (A) mean number of new nodes formed per terminal shoot and (B) number of *C.thysanura* nymphs per terminal shoot.

shooots of the infested plants was observed. Infested young 12-month old plants ceased growth 84 days after infestation (Fig. 9). On mature plants, new nodes formed per terminal shoot on the infested (unsprayed) plants but at a reduced rate (Fig. 10a). However, the mature plant did not cease growth, indicating better tolerance to psyllid attack.

3.3 Effect of *C. thysanura* feeding on the number of boronia flowers produced.

Psyllid-infested glasshouse maintained plants produced significantly fewer ($P<0.01$) flowers per terminal shoot (19.00) than uninfested plants (43.75) (Table 15), a 56.6 per cent reduction in flower yield. The unsprayed field plots produced 19.40 flowers per terminal shoot which was significantly less ($P<0.01$) than the yield of 33.80 flowers per shoot in monocrotophos sprayed plots (Table 16). The total flower yield (kg) of the unsprayed plants was 38.80 kg which was significantly less ($P<0.01$) than 66.40 kg in the sprayed plot (Table 17). The mean yield of the 60 plants in each replicate was 5.54 kg for unsprayed plots and 9.49 kg for sprayed plots (Table 17). The difference was significant ($P<0.01$).

However, there was no significant difference in the average weight of individual flowers ($P>0.05$) from both sprayed and unsprayed plots (Table 18). Using Judenko's (1973) analytical procedure to estimate the percentage economic yield loss caused by *C. thysanura* relative to flower yield of boronia plants, it was found that the psyllid can cause an economic yield loss of 41.7 per cent (Table 19).

Table 15
Mean number of flowers per terminal shoot of *C. thysanura* infested and uninfested boronia plants in the glasshouse. (mean results of 8 replicates).

Treatments	No.of flowers/terminal shoot
Infested plants	19.00a
Uninfested plants	43.75b
Total	62.75

Lsd(0.05)=6.80;Lsd(0.01)=10.07
Means are significantly different at ($P<0.01$),Duncan's multiple range test.

Analysis of variance table for Table 15

Source of variance	Degrees of freedom	Sum of squares	Mean square variance	F
Treatments	1	2450.25	2450.25	74.0097**
Replications	7	211.75	30.25	0.9137
Error	7	231.75	33.1071	
Total	15	28930.75	2513.6071	

Table 16

Mean number of flowers per terminal shoot on sprayed and unsprayed boronia plants at Copping during the period December 1987-August 1988. (mean of 10 replicates).

Treatments	No.of flowers/terminal shoot
Sprayed plants	33.80a
Unsprayed plants	19.40b

Lsd(0.05)=4.42; Lsd(0.01)=6.35

Means followed by the same letter are not significantly different,P>0.05), Duncan's multiple range test.

Analysis of variance table

Source of variance	Degrees of freedom	Sum of squares	Mean square variance	F
Treatments	1	1036.80	1036.80	52.0714**
Replications	9	128.80	14.11	0.7187
Error	9	179.20	19.91	
Total	19	1344.80	1070.02	

Table 17

Mean flower yield (kg) on sprayed and unsprayed boronia plants at Copping during the period December,1987-August,1988.

Replications	Monocrotophos protected (sprayed) plot	Unsprayed plot
1	8.70	5.54
2	9.75	6.00
3	8.98	6.10
4	10.68	5.80
5	9.58	5.38
6	10.21	5.45
7	8.50	4.61
Total	66.40	38.80
Mean	9.49a	5.54

Lsd(0.05)=0.70; Lsd(0.01)=1.06

Analysis of variance

Source of variance	Degrees of freedom	Sum of squares	Mean square variance	F
Treatments	1	54.4114	54.4114	189.6891**
Replications	6	3.6766	0.6128	2.1363
Error	6	1.7211	0.2868	
Total	13	59.8091	55.3110	

Fig.11

C. thysanura damage to Boronia megastigma.

In Table 20, in which the percentage flower yield loss (kg) in the unsprayed and sprayed plots was calculated without using the Judenko (1973) analytical procedure, the economic flower yield loss due to *C. thysanura* was calculated to be 41.6 per cent which approximates with the value of 41.7 per cent calculated using Judenko's (1973) method. It was observed that each node on a boronia plant was capable of producing two flowers.

3.4 The effect of psyllid feeding on oil yield

Solvent extraction of flowers from sprayed and unsprayed boronia plants revealed that the oil yield (fresh weight basis) of unsprayed plots was significantly reduced ($P<0.001$) by psyllid feeding (Table 21).

3.5 Damage - population density of psyllids

The damage-density potential test indicated that an intense *C. thysanura* population was capable of causing noticeable damage to boronia plants (Table 22 and Fig. 12). The number of new nodes formed per terminal shoot of boronia plants subjected to different population densities significantly decreased ($P<0.05$) as the population density increased (Fig. 12 and Table 22). At infestation levels of 10, 20, 30, 40, 50 and 60 nymphs per shoot, respectively, the mean number of new nodes formed per terminal shoot were 10.00, 8.20, 7.60, 6.60, 6.40 and 5.80, respectively (Table 22). The differences were significant ($P<0.05$) with the exception of 20 and 30 nymph levels of infestation (Table 22). There were no significant differences ($P>0.05$) between the effects of population densities of 40, 50 and 60 nymphs per shoot (Table 22 and Fig. 12). It is, however, shown in Table 22 and Fig. 12 that 10 psyllid nymphs per terminal shoot caused less damage ($P<0.05$) to the growth of the terminal shoot than did levels of 20, 30, 40, 50 and 60 nymphs per shoot.

Table 18

Mean weight (g) of 50 boronia flowers from sprayed and unsprayed boronia plants in Copping,1987-88.

Replications	Sprayed plots(g)	Unsprayed plots(g)
1	2.48	2.20
2	2.40	2.29
3	2.13	2.23
4	2.20	2.49
5	2.43	2.35
6	2.48	2.23
7	2.29	2.40
Total	16.41	16.19
Mean	2.34a	2.31a

Overall mean wt/flower(sprayed plot)= 0.047g;

" " Unsprayed plot= 0.046g

Analysis of variance

Source of variance	Degrees of freedom	Sums of squares	Mean square variance	F
Treatments	1	3.5F-03		0.1604 NS
Replications	6	0.055	0.0092	0.4250
Error	6	0.1293	0.0216	
Total	13	0.1878	0.0308	

Lsd(0.05)=0.17 NS Lsd(0.01)=0.24 NS

Table 19

Estimation of boronia flower yield loss by *C.thysanura* infestations at Copping as estimated by the Judenko (1973) procedure.

Parameters	Value
Total number of plants (T)	= 420
Percentage of attacked plants (P)	= 100
Number of attacked plants (NAT)	= 420
Actual yield(unsprayed plants)/unit crop area(ACT)	= 38.80kg/90m2
Mean yield per unattacked plants (a)	= 0.158kg
Mean yield per attacked plants (b)	= 0.092kg
Actual loss = (a-b) NAT	= 27.72kg/90m^2
Expected yield in the absence of attack	= Loss+ ACT
	= 66.52kg/90m^2
Per cent economic loss	= Yield lossX100 / Expected yield
	= 27.72X100 / 66.52
	= 41.7 per cent

Table 20

Calculated flower yield loss on sprayed and unsprayed plots at Copping, 1987-88

Total yield from monocrotophos protected plots	= 66.40kg/90m^2
Total yield from unsprayed plots	= 38.80kg
Loss in yield	= 27.6kg
Per cent loss in yield	= 41.60 per cent

Table 21

Comparison of the per cent oil extracted (fresh weight basis) from flowers of sprayed and unsprayed boronia plants at Copping during the period December,1987-August,1988. (mean of 5 replicates).

Treatment	Mean % oil extracted(fresh weight basis)
Sprayed plants	0.71a
Unsprayed plants	0.48b

Lsd(0.05) =0.10; Lsd(0.01) =0.17 Means followed by different letters are significantly different at P<0.01, Duncan's multiple range test.

Analysis of variance table

Source of variance	Degrees of freedom	Sum of squares	Mean square variance	F
Treatments	1	0.1323	0.1323	40.3817**
Replications	4	0.0129	0.0032	0.9847
Error	4	0.0131	0.0033	
Total	9	0.1583	0.1388	

The results in Fig. 12 and Table 22 also show that 40 nymphs per terminal shoot can successfully suppress the formation of new nodes as can 50 and 60 nymphs per terminal shoot. Increasing the infestation levels of *C. thysanura* nymphs from 20 to 30 per terminal shoot does not have any significant effect (P>0.05) on the formation of terminal shoots (Table 22). However, as infestation levels on the plant increased to 40 psyllids per terminal shoot, significantly fewer (P<0.01) nodes were produced (Table 22 and Fig. 12). In a trial established in early April to June, 1988 ,with 2 and 5 nymphs per terminal shoot, it was found that the mean number of new nodes formed

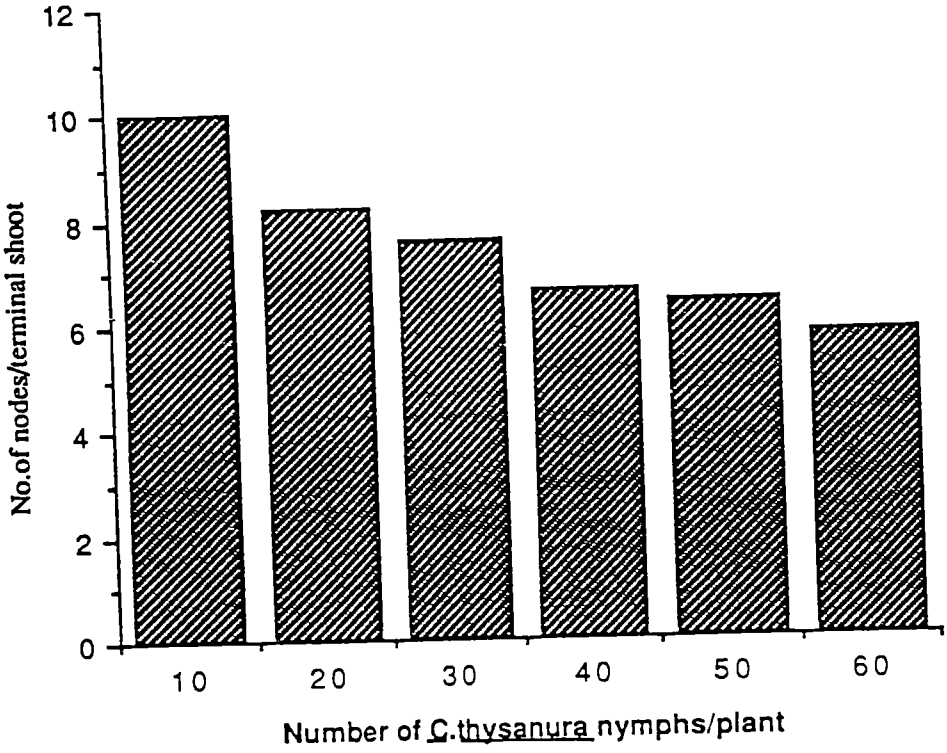


Fig.12

The effect of numbers of *C.thysanura* nymphs per boronia plant on the number of new nodes formed per terminal shoot under glasshouse conditions.

per terminal shoot was 12.80 with an infestation of two psyllids and 12.40 when the infestation level was 5. It was also shown that one out of the five plants used in the experiment at the higher infestation level of 5 had its terminal tip killed. No such mortality was observed at the lower infestation level. These results are shown in (Appendix 5). In this experiment, two flowers per node occurred on each of the plants subjected to the two infestation levels. However, a mean number of 25.60 flowers per terminal shoot was produced on plants infested with two psyllid nymphs per terminal shoot compared with 24.80 in the plants with five nymphs per terminal shoot (Appendix 5). The 1987 and 1988 trials were conducted under different photoperiods which resulted in more nodes in 1988 (equal days - equal nights) than produced in 1987 (short days - long nights). Accordingly, the 1987 results were taken for regression analysis (Fig. 13) since the photoperiod was more similar to that prevailing in the field experiments. A positive and significant relationship ($P<0.02$) between the psyllid population density and the number of plants with dead terminal tips was found (Fig. 14).

Table 22

The number of new nodes formed per terminal shoot on boronia plants infested with different population densities of *C. thysanura* nymphs during the period April-June,1987. (mean of 5 replicates).

Population density	Mean no.of nodes formed/terminal shoot
10	10.00a
20	8.20b
30	7.60b
40	6.60c
50	6.40c
60	5.80c
Total	44.60

Lsd(0.05) = 0.73; Lsd(0.01) = 0.98 Means followed by the same letter are not significantly different $P>0.05$; Duncan's multiple range test.

Analysis of variance table for Table 22

Source of variance	Degrees of freedom	Sum of squares	Mean square variance	F
Treatments	5	58.1667	11.6333	36.7368**
Replications	4	0.8667	0.2167	0.6842
Error	20	6.3333	0.3167	
Total	29	65.3667	12.1667	

3.5.1 Economic injury level

In the damage-population density trial, the regression of flower yields on *C. thysanura* densities was significant ($P<0.002$) with a negative slope, indicating that yield declined with increasing psyllid density (Fig. 13). The regression model for the flower yield-psyllid relationship was $Y = 20.3467 - 0.1566X$ ($r^2 = 0.9216$) where Y is the expected yield and X, the number of *C. thysanura* nymphs present per shoot.

To calculate an economic injury level (EIL), it was necessary to know not only the rate of yield reduction by the psyllid, but also the cost of controlling the insect and the market value of the crop. Monocrotophos was used by boronia farmers at 0.02% a.i. to control *C. thysanura*. The average cost of each application was A$27.17 per hectare, including tractor and labour costs. The market value of boronia flowers as paid by "Essential Oil of Tasmania Pty. Ltd." (EOT) on 0.70 oil yield (i.e., oil yield relative to fresh weight of flowers) was A$22.65 per kg of flowers including the cost of mechanical harvesting and EOT levy.

The "gain threshold", as referred to by Stone and Pedigo (1972), is the amount of yield loss that constitutes minimum economic damage. The following formula was used to calculate the gain threshold (Ogunlana and Pedigo 1974):

$$\text{Gain threshold (kg/ha)} = \frac{\text{cost of pest control (\$/ha)}}{\text{market price of crop (\$/kg flowers)}}$$

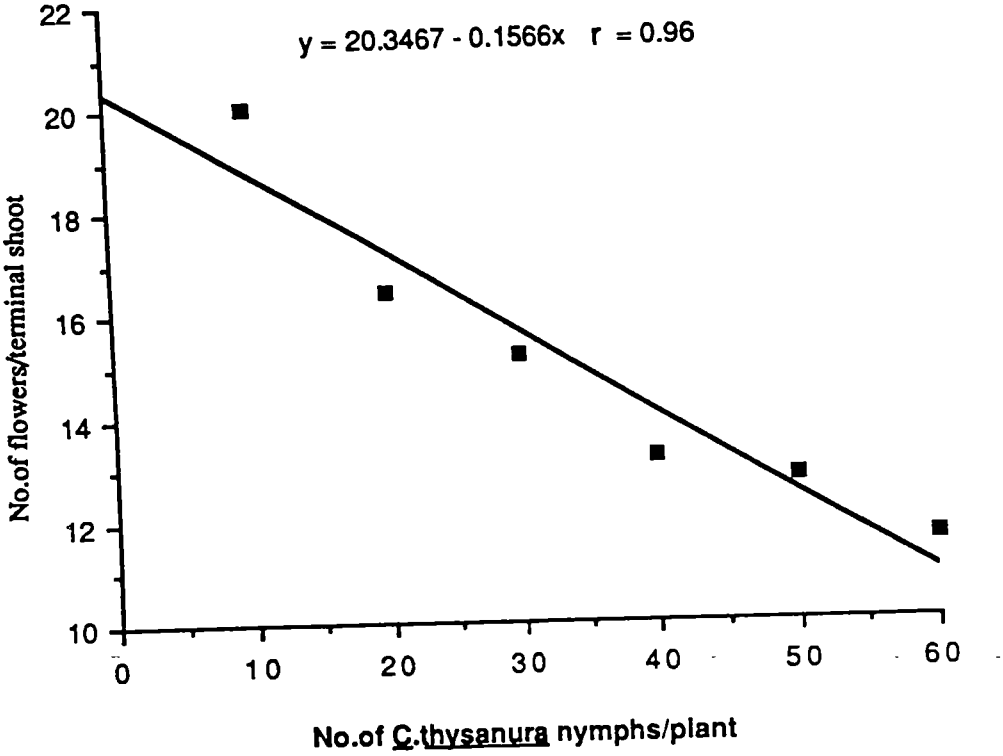


Fig.13

Regression of the flower yield per terminal bud of boronia plants on numbers of *C.thysanura* nymphs per plant.

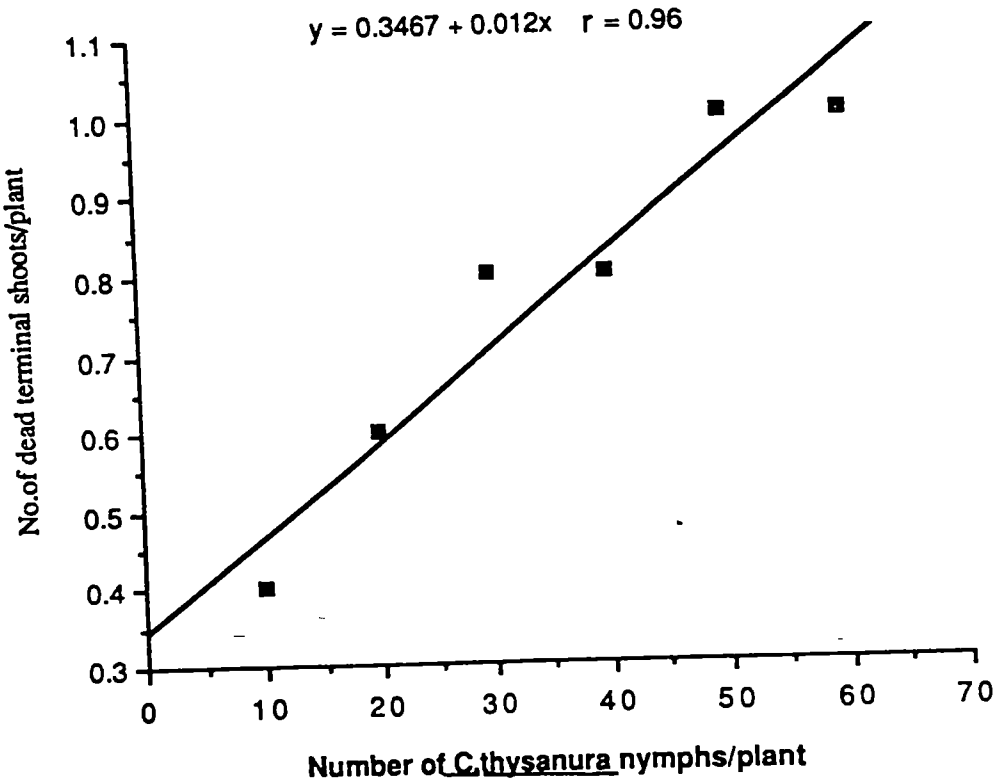


Fig.14

Effect of *C.thysanura* nymphal densities on mortality of terminal shoots/boronia plant.

$$= \frac{\$27.17/\text{ha}}{\$22.65/\text{kg}}$$

$$= 1.20\text{kg/ha}$$

The EIL was, therefore, the average number of *C. thysanura* per terminal shoot that would reduce the yield by 1.20kg/ha.

From the regression relationship,

because $Y = a + bx$, it follows that

$bx = Y - a = -(a - Y)$, but

$a - Y$ = reduction (the intercept minus the expected yield) = 1.20

Therefore, $bx = -(a - Y) = 1.20$. Using the equation of Fig. 13,

$bx = -0.1566x = 1.20$

therefore, $x = \frac{1.20}{0.1566} = 7.7 \approx 8$ nymphs

However, it is the fourth and fifth nymphal stages that cause significant and apparent damage. Consequently, the EIL for the 12 month old boronia plants used in this experiment was 8, fourth and fifth stage *C thysanura* nymphs per shoot.

4. Discussion

Results of the feeding experiment and subsequent examination of stained tissues indicated that *C. thysanura* feeds from phloem and bundle sheath cells. This type of feeding by *C. thysanura* nymphs is similar to that reported for *P. cockerelli* (Eyer 1937); *S. ericae* (Hodkinson 1973a); and *C. albitextura* (Clark 1962). Toluidine blue was used to stain transverse sections of leaves and gave excellent results staining lignin blue and cellulose, pink. Since the feeding tracks of the tubular nymphal stylets have no cells in them, they remained unstained and could be readily detected under the microscope. When feeding, *C. thysanura* nymphs made several punctures into the stem, possibly to detect a stomatal pore to reach the phloem tissues. *C. thysanura* confined its attack to young, actively growing boronia shoots approximately 15 cm long. Extreme *C. thysanura* feeding resulted in yellowing and abscission of leaves, cessation of growth and death of terminal shoots. This type of feeding behaviour and

damage has been reported for *H. cubana* attacking *L. leucocephala* in Western Samoa (Thomas and Liebregts 1987). Many mature host plants reacted by producing compensatory side shoots, but these were eventually attacked and the tip of the terminal shoot killed. Young plants up to 12 months old were extremely susceptible to damage and were often killed. Experimentally, it was shown that 12 month old infested plants ceased producing new nodes 56 days after initial infestation and growth entirely ceased within 84 days (i.e., after psyllids had completed two generations). Damage to the plant was cumulative and very much apparent as nymphs entered the fourth and fifth instars. On infested mature plants, the rate of production of new nodes was progressively retarded and the plant produced side shoots. This showed that the mature plants could tolerate psyllid attack. However, both the mature and the surviving young plants were stunted in comparison with uninfested control plants. Yellowing of the leaves due to psyllid infestation has also been observed in potatoes attacked by *P. cockerelli* (Eyer 1937). It was reported by Hodkinson (1973b) that feeding damage by most psyllid species was not severe and that *S. ericae* did not significantly affect shoot length, nutritive status and flower production of its host *C. vulgaris*. In contrast, damage by *C. thysanura* was very visible and severe and the appearance of damaged leaves and tips was similar to that of senescing plants.

During feeding, *C. thysanura* produces honeydew and, with high infestations, the boronia foliage becomes heavily contaminated with sugar-rich excreta and, in turn, black sooty mould. Such contamination suppressed plant growth. Excess honey dew also joined terminal leaves together, preventing tip growth and, during rain or irrigation, the tip of the terminal shoot rotted and died.

Each node produced two flowers and psyllid feeding suppressed flower production and total flower yield (Tables 15, 16, 17 and 18). The reason for the lower flower production on the unsprayed plot compared with the sprayed low infestation plot was that *C. thysanura*, especially the early nymphal stages, overwinter in the flowers (sepals, petals and bracts) and feeding results in abortion of flowers during strong winds. In addition to the direct loss of flowers, the most significant losses resulted from the reduction in the number of new nodes per terminal shoot due to infestation. Therefore, *C. thysanura* flower production was reduced in both direct and

indirect ways.

The percentage economic loss of boronia attacked by *C. thysanura* in the 1987/88 season was 41.7 per cent (Table 19) which means that the inability of the grower to control the psyllid in any one season can result in the total destruction of the boronia crop or plants. *C. thysanura* also suppresses the yield of oil extracted. The amount of oil extracted from flowers from the unsprayed plots was 0.48 (fresh weight basis) and that from the protected, sprayed plots was 0.71 (Table 21). This represented a 32.4 per cent monetary loss to the boronia grower. The reason for the reduced oil yield could be explained on the basis of the psyllid attack. Both adults and nymphal instars of *C. thysanura* overwintered on the host plant. During May, female psyllids lay eggs in the flower bracts and sepals enclosing the developing flower bud. After eclosion, the early nymphal instars fed in the flower bracts and sepals presumably on the photosynthate sent to the flowers and their presence might misdirect the photosynthate hence reducing oil accumulated in the flowers. When the flowers started opening in early August, the late nymphal instars moved to the flowers and sheltered in the petals and continued feeding. This feeding obviously reduced the efficiency of oil production so that accumulation in attacked plants was significantly reduced. The effect of green stink bug on the oil content of soybeans, *Glycine max* (L) Merr., has been reported by Daugherty *et al* .(1964). White (1970b) suggested that psyllid adults have a lower requirement for nitrogen than do nymphs so that increasing nitrogen in the food is not critical except for the female which continues to develop and lay eggs over a long period; this would certainly require a high quality nitrogen source. In these studies, the effect of *C. thysanura* feeding on the plant was apparent when the population consisted mainly of fourth and fifth stage nymphs.

The economic injury level determined on the basis of the damage-density trials showed that an average of 8 mature psyllid nymphs per terminal shoot on 12 month old boronia plants was capable of causing significant economic damage. Considering leaf hopper studies with alfalfa (Granovsky 1928), other legumes (Poos 1929) and soybeans (Ogunlana and Pedigo 1974), it is fairly safe to postulate that such economic injury levels are not likely to show extensive deviations from linearity. All these workers showed that the amount of injury produced by *Empoasca fabae* (Harris) was

apparently directly proportional to the number of insects present (other conditions being equal). Although the economic injury level established in this study appeared to be constant for 12 month old boronia plants, it should be noted that the economic injury level is a dynamic parameter being influenced by a number of factors. Variation in the economic injury level with the age of the plant is a fact which has been emphasised by Ogunlana and Pedigo (1974). The economic injury level calculated in this work is valid only for 12 month old and younger boronia plants.

Observations on the response of established mature plants would indicate that the slope of the regression curve would most likely decline because of the demonstrated tolerance. Results discussed in Chapter 5 would indicate that an EIL of 20 mature nymphs per terminal shoot could apply for mature plants. The EIL would also change for a given plant variety in a particular geographical area. It would change with any alteration to (1) market value of the boronia flowers and (2) cost of control measures. However, unless environmental changes are great enough to cause gross changes in the tolerance of boronia plants or feeding behaviour of *C. thysanura,* new EIL's can be calculated for changes to market value and control costs.

In 1988, it was found trials where infestation levels of 2 and 5 nymphs were used, that 5 nymphs per terminal shoot could kill the tip of the terminal shoot of 12 month old boronia plants. Although it was calculated that 8 psyllid nymphs per terminal shoot was the EIL, the grower could decide to spray when there were 4-6 nymphs per terminal shoot on young boronia plants to ensure minimum risk to the crop. This, therefore, becomes the economic threshold for the grower. The population dynamics studies (Chapter 5) indicate that the average number of nymphs per shoot should be obtained from 70 randomly collected terminal shoots. During the 1988 trials, greater numbers of new nodes were formed as compared with the 1987 trials because of the plants' exposure to a 12 L : 12 D regime. Because the 1987 trials were exposed to the same normal photophase as plants under field conditions, the results were employed to develop the EIL.

Chapter 5

The life history, behaviour and population dynamics of *Ctenarytaina thysanura* on *Boronia megastigma*

1. Introduction

The life history, behaviour and population dynamics of *C. thysanura* infesting *B. megastigma* were investigated on farms at Copping (eastern Tasmania), Kingston, Summerleas and Howden (southern Tasmania) and East Sassafras and Bakers Beach (north-western Tasmania). The farms, each of which had a history of regular *C. thysanura* infestations, are owned by members of the Boronia Growers' Association.

Populations were sampled from October 1986 to June 1989 at Kingston and Copping for nine generations; and from October 1988 to June 1989 at Summerleas and Howden, each three generations and for two generations at East Sassafras and Bakers Beach. Life tables were constructed from the data for each study area and analysed to recognise the key factors acting on the *C. thysanura* populations. Factors that affected the population dynamics of *C.thysanura* including the quantity of available food, fertiliser application, pruning of terminal shoots, crowding, emigration, parasitism, predation, harvesting of boronia flowers and weather are discussed in the light of findings from glasshouse and field studies. Factors influencing the flight phenology of *C. thysanura* are also discussed as well as the mode of overwintering of all stages of the insect.

2. Materials and Methods

2.1 Study areas

The life history, behaviour and population dynamics of *C. thysanura* were studied on boronia crops at Copping (eastern Tasmania) and Kingston (southern Tasmania) in

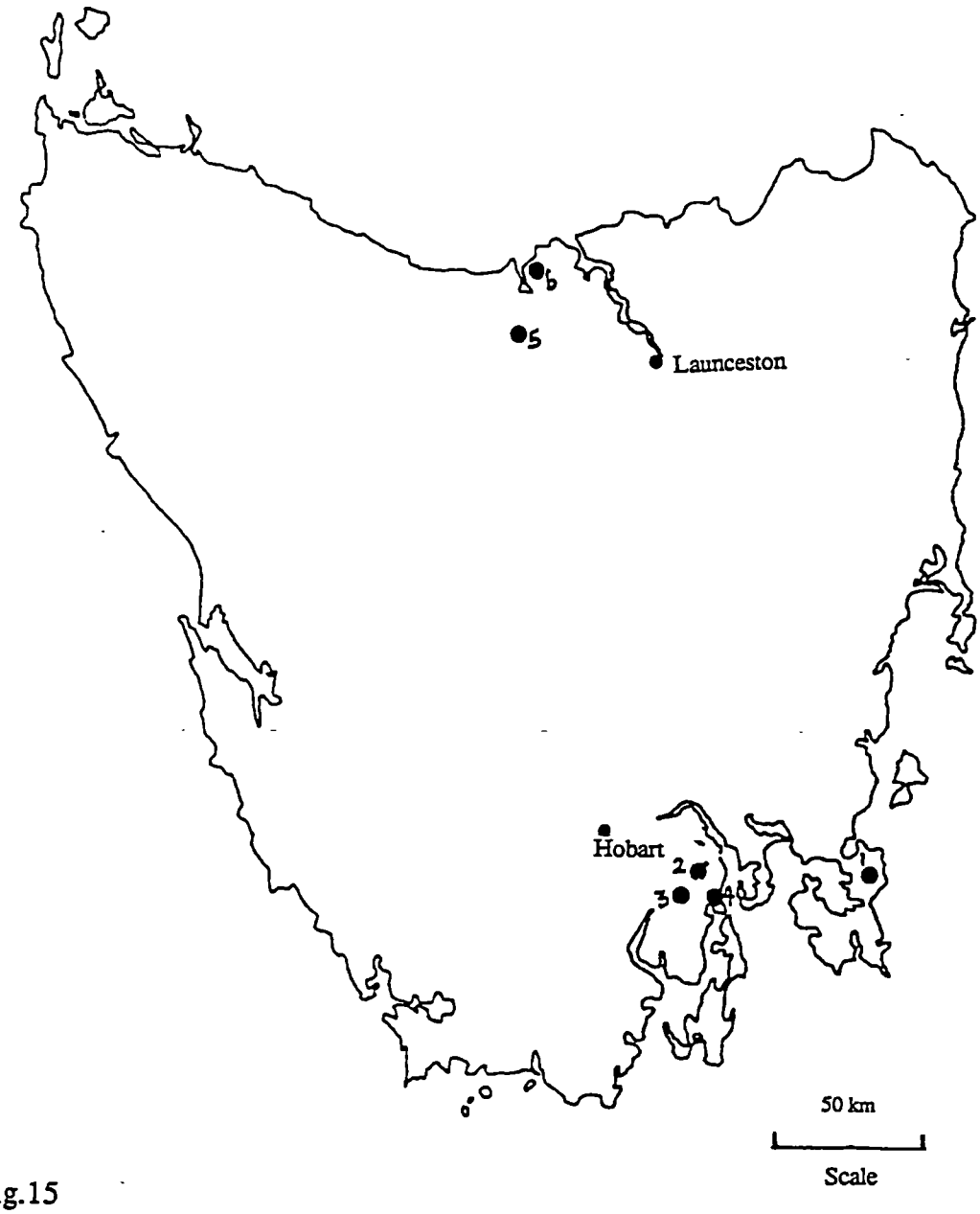


Fig.15

Sites throughout Tasmania where studies were made on *C.thysanura* populations. 1, "Copping" 2, "Kingston" 3, "Summerleas" 4, "Howden" 5, "East Sassafras" 6, "Bakers Beach"

1986/89; Summerleas and Howden (southern Tasmania), 1988/89; East Sassafras and Bakers Beach (north-western Tasmania), 1988/89; and the University of Tasmania (Hobart, Tasmania),(Fig. 15).

2.1.1 Copping

The study was conducted on a 0.5ha plot of boronia in a low lying, swampy site (Fig16) located at latitude 42° 50'S and longtitude 147°30'E at an altitude of 4 m . The grey, sandy soil was neutral to slightly acidic with pH 6.5. The area, surrounded by tall eucalypt trees, was planted in the 1982/83 with a total of 7,500 boronia plants in 20 rows with spacings of 0.5m within rows and 1.5m between rows. The boronia plants were of the same height and age.

2.1.2 Kingston, Summerleas and Howden

These three study areas, each separated 10km from each other, are located around latitude 42°53'S and longtitude 147°20'E at an altitude of 55.2 m. Each area was surrounded by tall eucalypt trees. The grey, sandy soil had a near neutral pH. Boronia plants, younger than those at Copping, were planted with spacings of 0.5m within rows and 1.5m between rows. Plants at Kingston (Fig 17) were planted in 1984/85, at Summerleas (Fig 18) in 1984 and at Howden in 1982. All experimental plots measured 0.5ha. In each study area, plants were of the same age and height.

2.1.3 East Sassafras and Bakers Beach

These two study areas are situated on the north-west coast of Tasmania around latitude 41°11'S and longtitude 146°23'E at an elevation of 46.0 m. The study area at East Sassafras lies on the leeward side of a hill with a brown- red clay loam soil type. The 0.5 ha plots were planted with a total of 6,500 plants. The plants were planted in 1982 in thirty rows. Plant spacing was similar to that in the other areas.

At Bakers Beach, the 0.5 ha plot consisting of grey, sandy loams was planted in 1987 with a total of around 8,000 plants.

Fig.16
Study site at Copping.

Fig.17
Part of the study site at Kingston.

Fig.18
Study site at Summerleas.

2.2 Determination of sample size

No previous studies have been conducted on either *C. thysanura* or any other insect attacking *B. megastigma* hence, determination of the optimum sample size for studying *C. thysanura* on boronia formed an integral part of this study. Factors considered in determining the number of terminal shoots to be sampled included the accuracy of estimates, the manhours required to collect and process the samples and the economic damage to the flower-producing boronia shoots.

The boronia plant is grown for its flowers, the yield of which depends on the numbers of terminal shoots and new nodes produced by the plant. Any sampling programme that reduces the number of terminal shoots will affect the flower yield of the boronia plant. In this study batch samples of 20, 40, 50, 60, 70, 80, 90, 100 and 110, 15 cm long terminal shoots were randomly collected one shoot per bush and taken to the laboratory for assessment. The numbers of *C. thysanura*-infested and uninfested shoots were recorded and the standard error of the mean calculated. The time taken to process each sample was also recorded. A graph of the dependent estimates of standard error of the mean (S_{ex}), and time to process the samples were plotted against the number of terminal shoots sampled. The intersection of the two curves gave the sample size which was a compromise between the two parameters assessed, i.e., standard error and manhours.(Fig.19). The precision graph gave an optimal sampling size of 70 shoots with a standard error of approximately 0.05. Throughout the studies, unless otherwise stated, a sample of 70 terminal shoots, each measuring 15 cm in length, was randomly taken from the 0.5 ha plots which contain about 7,500 plants unless otherwise stated.

2.3 Method of sampling used in the study of the psyllid population

A single shoot sample was taken from the outer layer of each of the 70 bushes sampled in the study area and placed into a plastic bag (15 x 16cm), which was tied up to prevent the escape of adult psyllids. Terminal shoots were taken from each row of boronia bushes, with the bushes randomly chosen within the rows. On return to the laboratory the leaf axils of individual shoots were opened immediately with pairs of forceps to expose insect stages under a binocular microscope. The numbers of eggs,

the five nymphal instars and adults, (male and female), were counted before the nymphs moulted to the next stage. Samples were taken at a regular interval of ten days throughout the study period from 1986-89.

In 1988/89, intensive studies were conducted in the other study areas: Summerleas, Howden, East Sassafras and Bakers Beach, to determine whether the generations of *C. thysanura* in these areas synchronised with those at Copping and Kingston, the major study areas. Only number of nymphs alive in the terminal shoots were recorded since dead nymphs dry up and fall off the terminal shoot. The numbers of predators found on the terminal shoots were recorded separately. The numbers of parasitised nymphs, recognised by the swollen body and the black or orange-brown colour change of dead mummies, were recorded.

To sample adults, boronia bushes in the study area were swept with sweep nets and adults and other insect fauna, including parasitoids and predators, counted in the laboratory. On each sampling day, 100 sweeps were made in the study area with one sweep per boronia bush, each bush having been randomly selected. Only the outer foliage of the top of each plant was swept and sweeping conducted every ten days following completion of the collection of terminal shoot samples.

2.3.1 The assessment of adult flight phenology in the study area.

The flight phenology of *C. thysanura* was assessed with yellow sticky traps. Eight yellow aluminium squares each measuring 30 x 30 cm, were supported in a furrow cut in a piece of PVC pipe (35 cm in diameter and 35 cm long) and placed 3 m apart in a row of boronia plants in the study area. The surface of each plate were smeared with Bird Tanglefoot (The Tanglefoot Company, Grand Rapids, Michigan, U S A. This study was conducted at both Copping and Kingston. Trap colour selection was based on the results described in Chapter 3, section 2.9. Psyllids caught on the traps were collected every ten days by careful removal with a small probe. Adults were sexed and counted in the laboratory. Following collection the traps were washed with kerosene, dried in the sun and recoated with the trapping adhesive before establishment in the field. Trap catches were compared with *C. thysanura* egg and nymphal populations in the terminal shoot to determine any relationship which might

indicate factors controlling flight activity.

2.3.2 The assessment of adult movement from the study area

To study the movement of *C. thysanura* adults out of the study area, an eight unattractive white sticky traps (30 x 30 cms) were supported on wooden poles 1.50 m above ground level located 100 m outside the study area at Copping. Adults were removed from the traps every ten days and the numbers of males and females recorded. Searches had failed to find *C.thysanura* on any other plant in the general area and it was assumed that psyllid adults captured were local. The number of adults caught during a particular generation was compared with the number of adults caught per sweep per bush to understand the movement of the psyllid adults.

2.4 Factors affecting psyllid populations

2.4.1 Effect of mechanical harvesting of boronia flowers

Boronia flowers once a year. Flower buds develop in autumn and the flowers mature in September, after which they are harvested. The female psyllid lays its eggs in autumn in the developing flower bracts, sepals and petals enabling the eggs to overwinter in the flowers. The first three nymphal instars also overwinter in the flowers.

The objective of this study was to determine whether mechanical harvesting of boronia flowers in September affected psyllid populations. The experiment was conducted at Copping. Plants in the study area were divided into two plots (plot 1 and plot 2) and 70 terminal shoots randomly taken from each plot 24 h before harvesting. The second plot served as a control and was left unharvested until two days after harvesting when 70 terminal shoots were again collected from each of the plots. The numbers of eggs, nymphs and adults of *C. thysanura* in the pre- and post-harvest samples were recorded and mortalities were calculated for both plots.

Sweep samples of adults were taken in both harvested and unharvested plots 24 h before and 48 h after harvesting.

2.4.2 Effect of terminal shoot pruning on psyllid populations

C. thysanura,like many other psyllids, is a phloem feeder and prefers the softer parts of the plant tissue and is therefore found in the leaf axils of terminal shoots of boronia plants. A study was conducted to determine the effect of pruning of terminal shoots following flower harvest on the psyllid populations of 3 year old boronia plants at Copping during the period October - December, 1987. In this study, plots measuring 3 m x 10 m, consisting of 20 boronia plants of the same age and height, were established. The dominant terminal shoots of the plants in the treated plots were pruned and the prunings removed from the plants and left in the rows. In the control plots, plants were left unpruned. This treatment application was replicated 7 times using a complete randomised block design. Pretreatment counts of psyllid stages per replicate plot were taken 24h before pruning. Post-treatment samples counts were taken at 7, 14, 21, 28, 35, 42, 49 and 56 days. Records were taken also of the number of *C. thysanura* eggs and nymphs in both the pretreatment and post-treatment counts. The experimental data was expressed as the numbers per terminal shoot on each sampling day and the data was analysed using analysis of variance.

2.4.3 Effect of fertiliser applications on psyllid populations

This study was conducted to determine the effect of nitrogenous fertiliser applications on the abundance of the psyllid population. The fertiliser used in this experiment was a mixture of two parts Osmocote (17N : 4.4P : 10K) supplemented with one part isobutylidene di-urea (IBDU 31%N).

At Copping, 3 m x 10 m plots containing 20 boronia plants, 3 years of age, were demarcated and plants fertilised with the above mixture at the rate of 5g per plant. As controls, identical plots were set up, but the plants were not fertilised. The trial was replicated 7 times. The experiment was commenced in October 1987 at Copping. Pretreatment counts were taken by randomly sampling 70 terminal shoots (i.e., 10 terminal shoots/replicate) from both fertilised and unfertilised plots. Post-treatment counts were taken at 10-day intervals for a period of 90 days after treatment application. Records were taken of the number of *C. thysanura* adults, both male and female, eggs and nymphs and the growth of the boronia plants.

The growth of the plants in each treated and control plot was assessed by the number of new nodes formed. In this assessment, 10 plants were randomly selected from each treated and control plot (one plant from each of replicates 1, 2, 3 and 4 and two plants from each of replicates 5, 6 and 7) and a terminal shoot from each plant was tagged by marking its tip with Olympic yellow paint. The number of new nodes formed from the yellow paint mark were counted every 10 days for 90 days. The data from the experiment was analysed by analysis of variance.

2.5 Laboratory techniques

2.5.1 Effect of crowding on psyllid populations.

This study was conducted during the period April 1987 - July 1987 and maintained at a temperature of 18-20^{o}C and a relative humidity of 65-75%. This experiment has already been described in Chapter 4 from the density-damage relationship where the economic injury level was assessed. This aspect of the experiment considers the effect of intraspecific competition on *C. thysanura* populations. Psyllid population levels of 10, 20, 30, 40, 50 and 60 nymphs, respectively, were established on 12-month old potted boronia plants which were enclosed in plastic cages as described previously. The experiment was replicated 5 times at each of the population densities. The nymphs of each treated plant were examined daily until all adults emerged. All adults emerging from each population level were sexed and weighed and the weight recorded. In this way, the number of nymphs that could turn adult at each population level was known; hence the mortalities at each level were recorded. Record was also taken of the developmental period and the number of males and females that emerged at each population density.

After adult emergence, five males and five mature females from each of the population density experiments were taken and a pair placed on a fresh boronia plant enclosed in a plastic bottle cage for oviposition. This was replicated five times for each population density. Eggs laid were counted every 10 days i.e., just before the eggs hatched, until the female psyllids died. This enabled the determination of the effect of crowding of the immature stages of *C. thysanura* on the number of eggs laid per

female of emerging adults. The data was subjected to analysis of variance and the means compared by Duncan's multiple range test.

2.5.2 Effect of crowding among psyllid adults

Mature 6 day old females were taken from a culture in the glasshouse and numbers of 1, 2, 3, 4, 5 and 6 females, were placed on the terminal shoot of individual boronia plants. The plants were the HC4 clonal variety developed at the University's Horticultural Department. Equal numbers of males were released on to the plants to mate with the females. Each plant was enclosed in a plastic bottle cage to prevent the psyllid adults from flying away. The experiment was replicated five times and was conducted in the glasshouse at a temperature of 18-20^{o}C. The total numbers of eggs laid by the female psyllids were counted and the data was also expressed as the number of eggs laid per female, The data was subjected to analysis of variance and the means compared by Duncan's multiple range test.

2.5.3 Effect of the quantity of available terminal shoots on *C. thysanura* oviposition rate.

Two pairs of 6 day old psyllids were placed on 10 month old potted HC4 boronia plants in each of 5 plastic bottle cages. The terminal shoots of the plants had been pruned to leave 1, 2, 3, 4 and 5 terminal shoots, respectively. The experiment was replicated five times in the glasshouse. The insects were left to feed and oviposit and die and the total numbers of eggs laid on each plant were counted and recorded. Average numbers of eggs per female were calculated from the total number of eggs. The number of eggs per terminal shoot was recorded to determine the spread of psyllid eggs among the terminal shoots. The data was subjected to analysis of variance and the means compared by Duncan's multiple range test.

2.6 Predation trials

Many predatory insects occurring with *C. thysanura* on boronia plants are possibly potential mortality factors. However, their effects are very difficult to study and cannot be easily duplicated in the laboratory. All the predators studied in this work

were observed to feed on *C. thysanura* in the field. Numbers of syrphid larvae occurring in the shoot samples were recorded and compared with the number of *C. thysanura* nymphs per terminal shoot to assess whether any significant relationships existed. Coccinellids, Trombidiid mites and true spiders, were sampled from *C.thysanura* sweepings and the number per sweep was compared with the number of *C. thysanura* adults and nymphs to detect any association between the two populations. The ratio of predator numbers to *C.thysanura* numbers was also calculated to determine the availability of psyllids to predators on boronia plants.

An attempt was made using the coccinellid, *Cleobora mellyi* (Mulsant), to determine the number of *C. thysanura* adults that could be consumed daily by the predator. Four coccinellid adults were captured from the field at Copping and starved for one day. Each predator was then added to caged boronia plants each of which had 4 terminal shoots with each shoot being infested with 40 late stage nymphs. Each test was replicated four times. Records were taken of the number of surviving nymphs remaining on each plant after 4 days, and hence the number eaten by the predator per day was determined. A control experiment was established in which no coccinellids were introduced onto the boronia plants containing the psyllid nymphs.

The data was subjected to analysis of variance and the means compared using Duncan's multiple range test.

2.7 Parasitisation trials

C. thysanura nymphs were attacked by a number of parasitoid species in the field. Parasitised nymphs are recognised by the swollen nature of the nymphs prior to death and the characteristic colour change of the dead psyllid mummies. Records were taken of the number of late nymphal stages parasitised or killed by parasitoids during shoot examination. The parasitised nymphs were kept in plastic bags in the glasshouse until the parasitoid emerged. Specimens of the parasitoids were sent to Dr I Naumann, The Australian National Insect Collection, C S I R O., Division of Entomology, Canberra, and Mr E A Dahms, Senior Curator (Entomology), The Queensland Museum, for identification.

2.8 Interaction of *C. thysanura* and *Aphis gossypii* Glover on boronia plants

The cotton aphid, *A.gossypii*, was first observed infesting boronia at Kingston in autumn, 1987, and afterwards in all study areas with exception of East Sassafras and Bakers Beach.

The interaction of aphids and psyllids on boronia plants was studied in the field and glasshouse.

2.8.1 Relationship of *C. thysanura* to *A. gossypii*

Records were taken of the numbers of *A. gossypii* collected when sampling *C. thysanura* populations. The ratio of *A. gossypii* (nymphs and adults) to *C. thysanura* adults was compared with the number of *C. thysanura* eggs per terminal shoot.

2.8.2 Effect of *A. gossypii* on the oviposition behaviour of *C. thysanura* females on boronia plants.

A glasshouse study was commenced in November, 1988. Apterous *A. gossypii* nymphs were obtained from a culture maintained outside the glasshouse since August, 1988. Two 6 day old female *C.thysanura* were caged on 10 month old boronia plants. The plants were infested with four *A. gossypii* nymphs and infested potted plants enclosed in plastic bottle cages. This experiment was replicated five times. In the control experiment, only psyllid-infested plants were used. Records were taken of the number of eggs laid by *C. thysanura* on both the aphid-infested and uninfested plants. Psyllid movement on the boronia plants was observed through the plastic bottle.

The data was subjected to analysis of variance and the means compared by Duncan's multiple range test.

2.8.3 Effect of the interaction of *C. thysanura* and *A. gossypii* on the growth of the boronia plants.

This study was conducted to determine whether the presence of *A. gossypii* on

boronia had any effect on (1) the growth of the plant (i.e., the number of new nodes formed) and (2) the degree of *C. thysanura* damage.

Four 12 month old boronia plants were established in the glasshouse. The first plant was infested with two pairs of *C. thysanura* adults (T1); the second was infested with four adult *A. gossypii* nymphs plus two pairs of psyllid adults (T2); the third was infested with four adult aphids only (T3); and the control plant left uninfested (T4). All plants were enclosed in a plastic bottle cage (as described in section 2.8.2). The experiment was replicated four times. Initially, two nodes were left on each treated plant and marked with yellow paint using a zero pin. The numbers of new nodes formed on each plant each week were counted from the yellow paint mark and recorded for 84 days post treatment when the T1 plants died.

The behaviour of the female psyllids on plants with and without aphids was observed. The results were subjected to analysis of variance and the means compared by Duncan's multiple range test.

2.8.4 Isolation and chemical identification of the droplets released from *A. gossypii* cornicles.

This study was conducted following experiment 2.8.3 to identify the potential cause of any abnormal behaviour between psyllids and aphids. Droplets were collected using the method of Wientjens *et al.* (1973) which involved directly immersing individual aphids (n=200) in hexane. Approximately 10 seconds after immersion, droplets were observed being released from the cornicles. For analysis the hexane extract was concentrated to approximately 20 µl and one µl analysed by GC-MS at the Central Science Laboratory. A one µl drop was injected into a Hewlett Packard 5890 gas chromatograph fitted with a 18m HP1 capillary column coupled with a Packard 5970 mass selective detector. Identification of materials present was made from their mass spectral characteristics.

2.9 Meteorological data

Thermohygrographs and a maximum and minimum thermometer (Brannan Thermometers, Cumberland, United Kingdom) were established at Copping in October

1986 to monitor temperature and relative humidity in the study areas. Continuous temperature and relative humidity records were maintained until the conclusion of the study. These data was compared with the maximum and minimum temperatures and relative humidity readings obtained from the Department of Science, Bureau of Meteorology for these areas. Monthly rainfall figures for the Copping and Hobart areas from 1958 to 1989 were used to determine rainfall trends in Copping and Kingston. Rainfall data for East Sassafras and Bakers Beach, were obtained from the East Devonport weather station.

2.10 Analysis of the sampling data

2.10.1 The expression of sampling results

Population estimates for eggs, nymphs and adults were expressed as numbers per terminal shoot, unless otherwise stated. In using the sweep net to estimate the population of adults and predators in the study area, numbers were expressed as numbers per sweep or per bush since 100 sweeps (which is equivalent to 100 bushes) were made every sampling day. The peak number of adults per sweep for each generation in each of the study areas was compared with the number of adults per terminal shoot.

2.10.2 Construction of the life table

Life tables were constructed for populations of *C. thysanura* for nine generations at Copping and Kingston, 1986-89; three generations at Summerleas and Howden, 1988-89; and two generations at East Sassafras and Bakers Beach, 1988-89. In all these life tables, population estimates of *C. thysanura* eggs, nymphs and adults in each generation were expressed as numbers per terminal shoot. Adults per terminal shoot were compared with the numbers of adults per sweep per bush.

The generation life tables were analysed using Varley and Gradwell's (1968) key factor method which enables the recognition of key factors acting on the populations and the period over which they act. For this analysis, estimates of density at different

progression stages were expressed logarithmically and the difference between successive logarithmic density values was termed *k*, and total generation mortality *K*, was equal to the sum of the *k's* for all stages. This analysis permits the determination of the role of the mortality factors at each stage of the life cycle of *C. thysanura* and the recognition of any density relationships and the mode of action of 'key' factors.

In the life table analysis, the key factor was recognised initially by the visual correlation of the various stage mortalities (k-values) with total K generation mortality. The density relationship was identified by plotting the k-value of a particular stage against the log initial density of that stage on which the factor acted and the corresponding curve was tested against b=0. Density dependence was proved by plotting log numbers entering the stage (log N) against log number of survivors (log S) and vice versa. The regressions of the two curves (log N on log S; and log S on log N) were calculated and the regression coefficients were tested against b=1. A significant departure of the slopes of each curve from b=1 indicated that density dependence had really occurred (Varley and Gradwell 1968).

The proof for delayed density dependence was determined by plotting (or regressing) k on N_{t-1} then on N_{t-2}, then on N_{t-3}, where $k=\log_e N_t - \log_e N_{t-1}$, and N_t is the number entering a particular stage (eggs) in generation t. The anticlockwise spiral formed when each point is joined in time series will indicate a delayed density dependence and also if delayed feedback is important then best fits will be obtained with higher lags.

In the analysis of parasitism and predation, the k-value was plotted against log host density and the curve tested against b=0 and b=1. The k-values were joined in a time series to determine the type of density relationship from the patterns produced.

To determine whether parasites are determining changes in numbers, and also if parasites are regulating psyllid numbers in a delayed density dependent manner, the rate of population change from generation to generation was regressed on the number parasitized i.e, $k_{3-5}= \log_e N_t - \log_e N_{t-1}$ was regressed on P_{t-1}, where P_{t-1} is the number parasitized at time t or in generation t and the points were joined in time series. Also k_{3-5} was regressed on parasitoid-prey ratio.

In testing the slopes of the regression curves against b=0 and b=1, the student's t

statistic was used (Zar 1984). The t statistic is, in general, calculated as:

$$t = \frac{\text{(parameter estimate) - (parameter value hypothesized)}}{\text{standard error of parameter estimate } S_b}$$

$$= \frac{b - 0}{S_b} \quad \text{or} \quad \frac{b - 1}{S_b}$$

The standard error of the regression coefficient S_b needed to be computed.

The standard error of the estimate is directly related to the coefficient of non determination and to the variability of Y as $S_{y.x} = \sqrt{1 - r^2}$ (Zar, 1984). The variance of the slope of the regression b was calculated as

$$S_b^2 = \frac{S^2_{y.x}}{\Sigma x^2} \qquad \text{Therefore, } S_b = \frac{\sqrt{S^2_{y.x}}}{\Sigma x^2}$$

and $t = \frac{b - \beta 0}{S_b}$ or $t = \frac{b - 0}{S_b}$ or $\frac{b - 1}{S_b}$

However, Richards' (1940) method was also used to calculate age-specific mortalities and these figures were compared with those obtained from the Varley and Gradwell analysis. It is assumed in the method that the number of each nymphal instar found in a series of systematic samples corresponds with the time spent in that instar and that any difference represents the magnitude of the mortality for that instar. In using Richards' (1940) method, the duration of each stage for each generation was calculated from day- degrees using the results of a glasshouse study of the duration of the specific stages of *C. thysanura*. The results are shown in Appendix 7-10 for all study areas. However, Varley and Gradwell's (1968) method gave the most consistent results.

3. Results and observations

3.1 Sample size determination

A sample size of randomly selected 70 terminal shoots per boronia plant is required at each sampling date for *C. thysanura* population assessments. This sample size gives a standard error of 0.05, and takes ca. 125 minutes to process in the laboratory (Fig. 19).

Table 23 shows the number of dominant terminal shoots per plant at six study areas during the period 1986-89.

Table 23

Counts of dominant shoots per plant recorded annually after the spring generation for the period 1986-89 at the study areas.(Mean results of 50 plant).

Study area	Mean no.of dominant terminal shoots/plant			
	1986	1987	1988	1989
1. Copping	400	450	310	260
2. Kingston	40	45	52	74
3. Summerleas	-	-	29	40
4. Howden	-	-	36	44
5. East Sassafras	-	-	55	62
6. Bakers Beach	-	-	22	12

3.2 Life cycle

3.2.1 Overwintering stages, sites and forms of *C. thysanura*

C. thysanura overwinters successfully within leaf axils the egg and nymphal

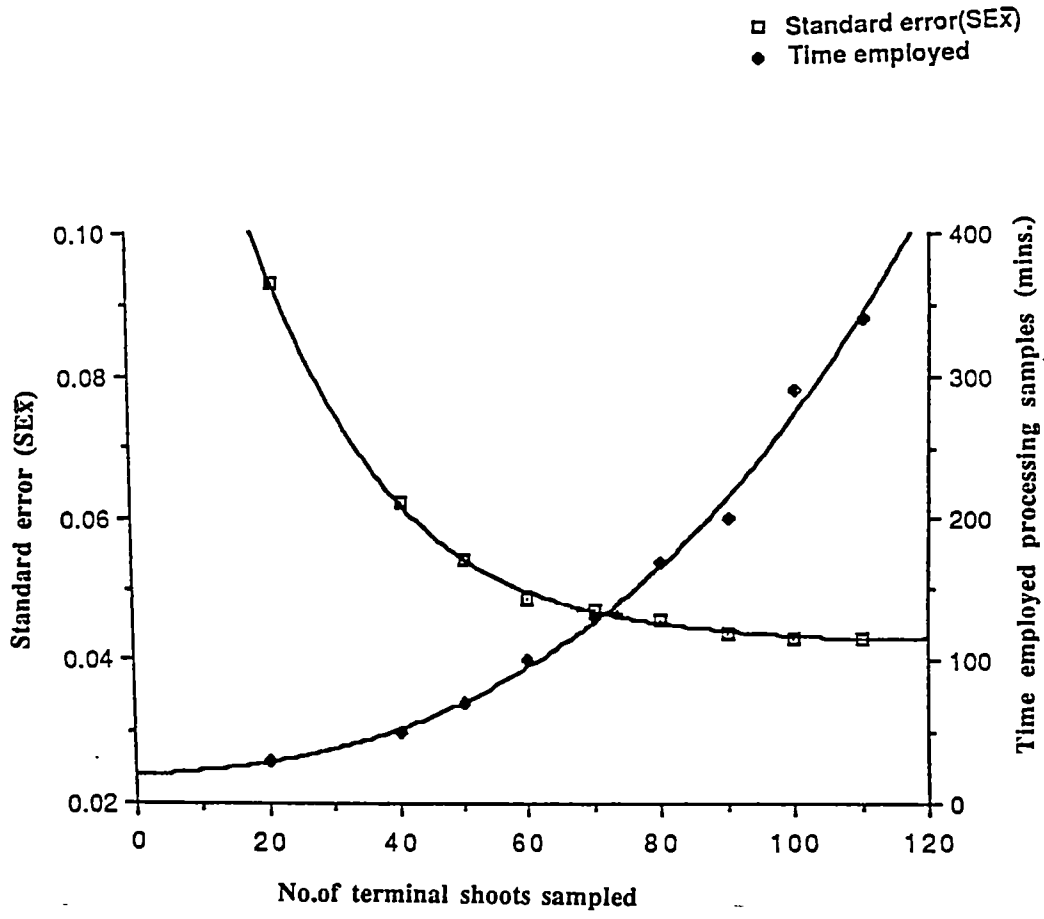


Fig. 19

Precision graph showing a compromise between manpower expended and the accuracy of results to determine the sample size of boronia terminal shoots in *C.thysanura* assessments.

instars, and, during mild winters, adults also overwinter. The egg and early nymphal instars (first - third) overwinter in the flower bracts, sepals and petals of boronia plants. There was a negative correlation ($P<0.001$) between the number of *C. thysanura* eggs and early nymphal instars in the flowers and the mean daily temperature at Copping and Kingston (Figs. 20 and 21). The adult females lay eggs in the developing flower buds during the onset of winter and about 50 per cent of psyllid eggs were found in the flowers when the mean daily temperature dropped to 10°C at both Copping and Kingston (Fig. 20). The early nymphal instars which were in the leaf axils of the terminal shoots also sheltered in the flowers and about 50 per cent of the nymphal population was found in the developing flower buds when the mean field temperature was 9.8°C (Fig. 21).

The large late nymphal stages were unable to occupy the developing flower bracts and sepals and overwinter in the leaf axils of the terminal shoots. Survival in such an exposed site is some way assissted by the development of a dark pigment in the body surface(Fig.23). The development of the dark pigment of the late nymphal instars correlated negatively ($P<0.001$) with the mean daily temperature (Fig. 22). Fifty per cent of the total population of fourth and fifth nymphal instars of *C.thysanura* at Copping and Kingston had developed dark pigment in the body surface when the temperature dropped to 9-10°C.

3.2.2 The flight activity of *C. thysanura* adults within the study area

The flight activity of *C. thysanura* adults at Copping and Kingston during 1986-1989 is given in Fig. 24. *C. thysanura* adults are in flight most often within the boronia farm with the greatest flight activity occurring in May (autumn) and September-October (early spring); with the summer flight usually occurring in January-February; and very little flight activity during the cold, winter months. The flights of male and female adults are positively correlated ($P<0.001$), indicating that both sexes are in flight together (Fig. 25). *C. thysanura* adult flight activity is positively correlated with the peaks of numbers of *C. thysanura* eggs ($P<0.01$) and nymphs ($P<0.10$) in the leaf axils of the host plant (Figs. 26 and 27).

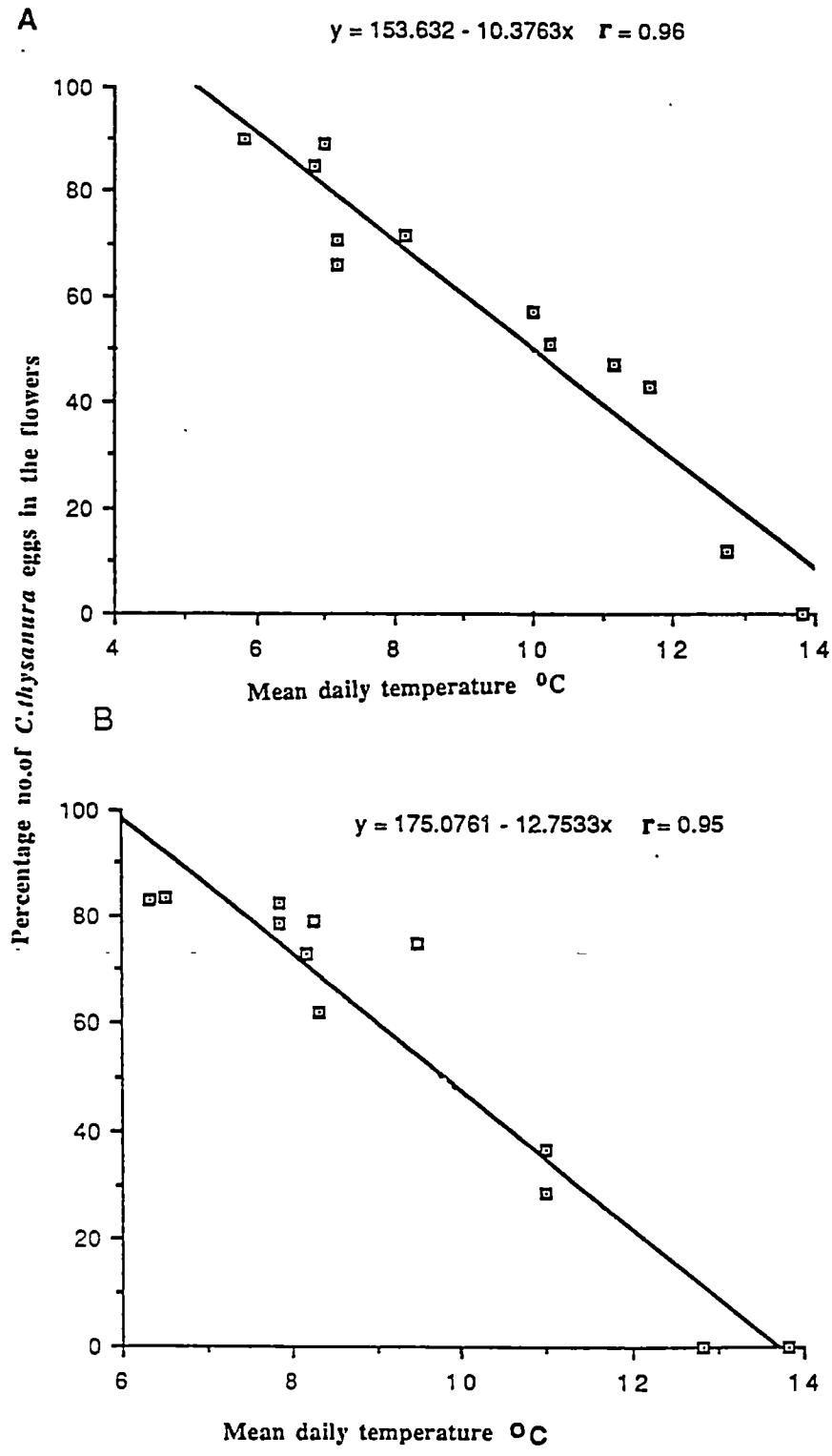


Fig. 20

The relationship between mean daily temperature and the percentage number of overwintering *C.thysanura* eggs in the boronia flowers (bracts,sepals and petals) during 1987 and 1988 winter months in the study areas at (A) Copping, and (B) Kingston.

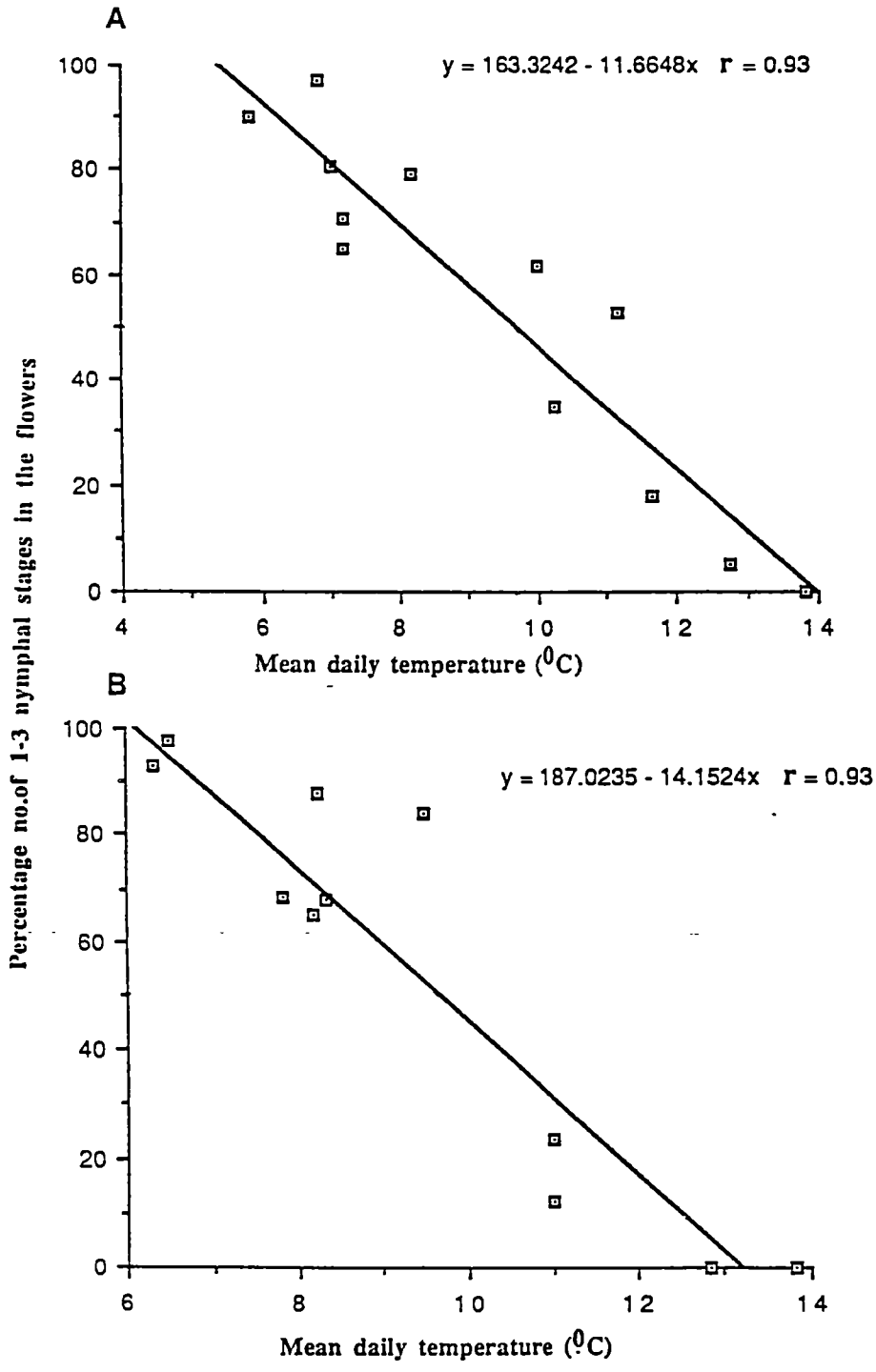


Fig.21

The relationship between mean daily temperature and the percentage number of overwintering 1-3 nymphal stages of *C.thysanura* in the boronia flowers (bracts,sepals and petals) during the 1987 and 1988 winter months in the study areas at (A) Copping, and (B) Kingston.

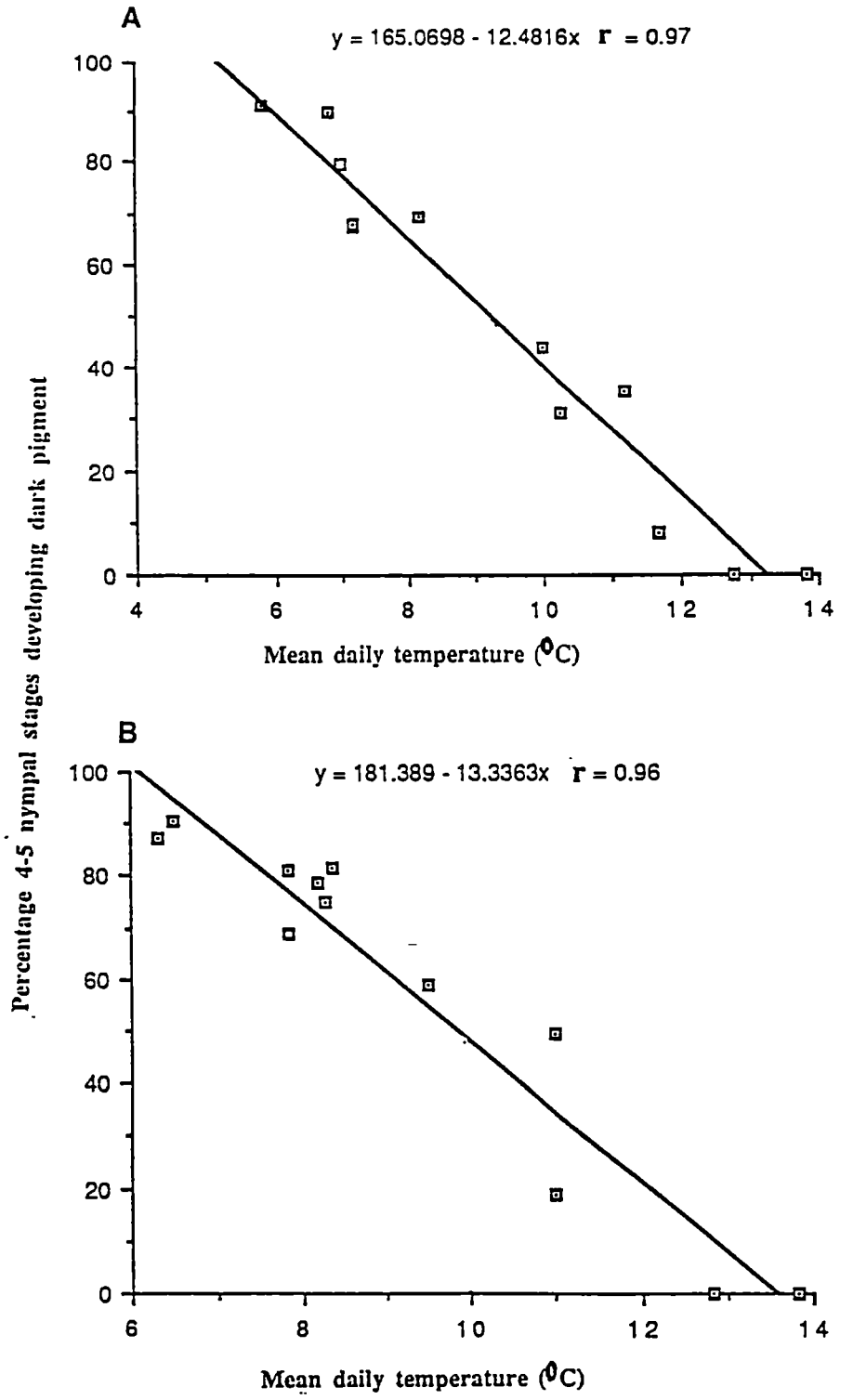
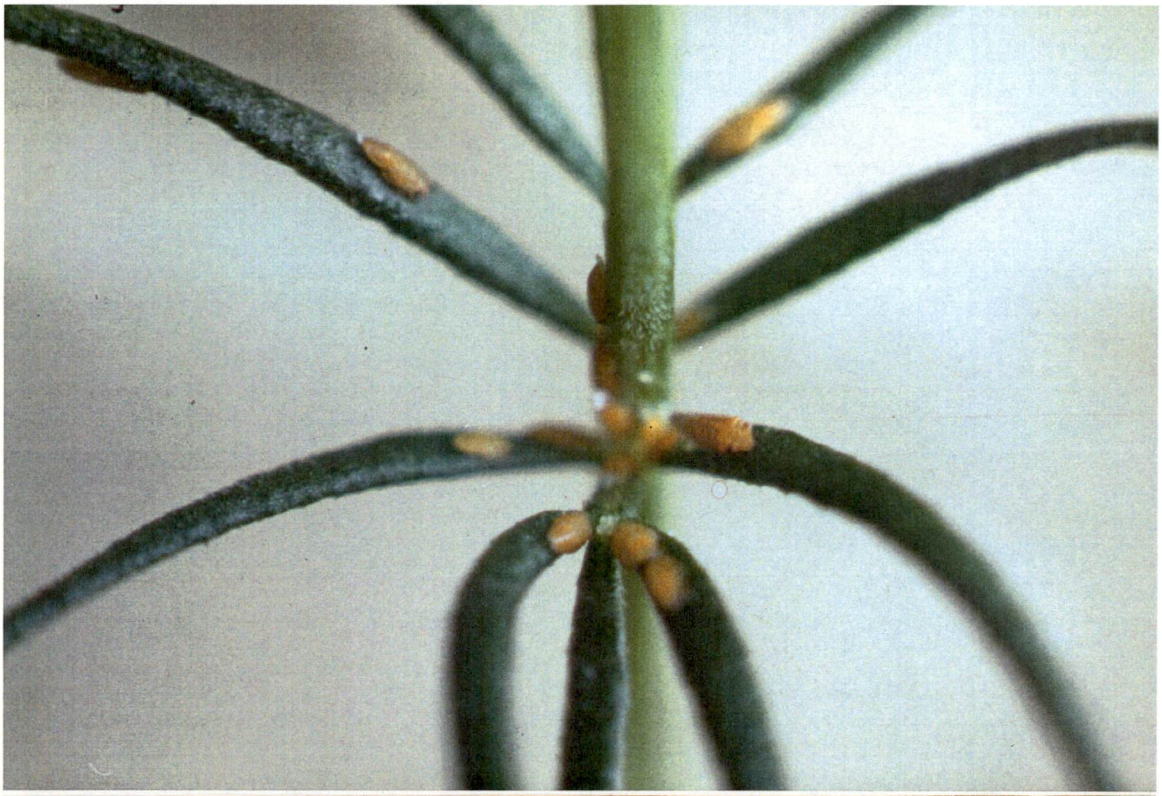


Fig. 22

The relationship between mean daily temperature and the percentage number of overwintering 4-5 nymphal stages of *C.thysanura* developing dark pigment during the 1987 and 1988 winter months in (A) Copping, and (B) Kingston.

1



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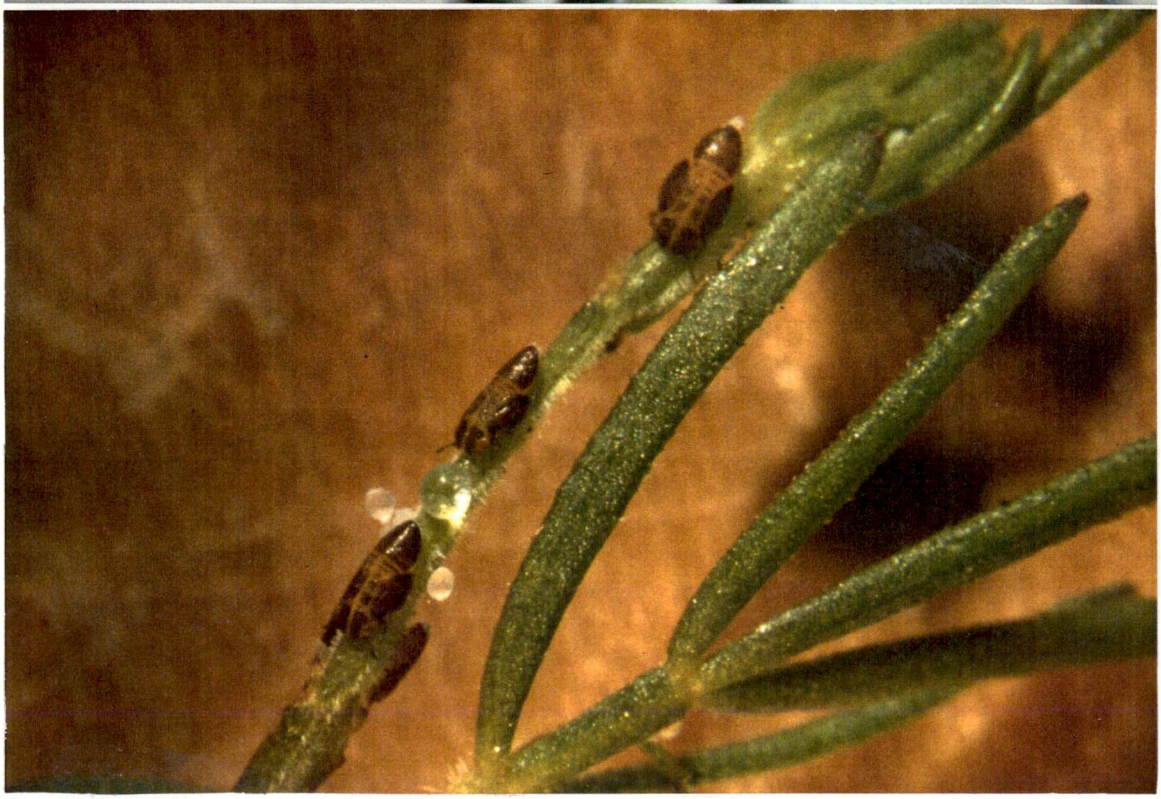


Fig.23

C. thysanura (1) Summer (x 1) and (2) winter (x2) forms of the 5th nymphal stages, the latter showing dark pigmentation.

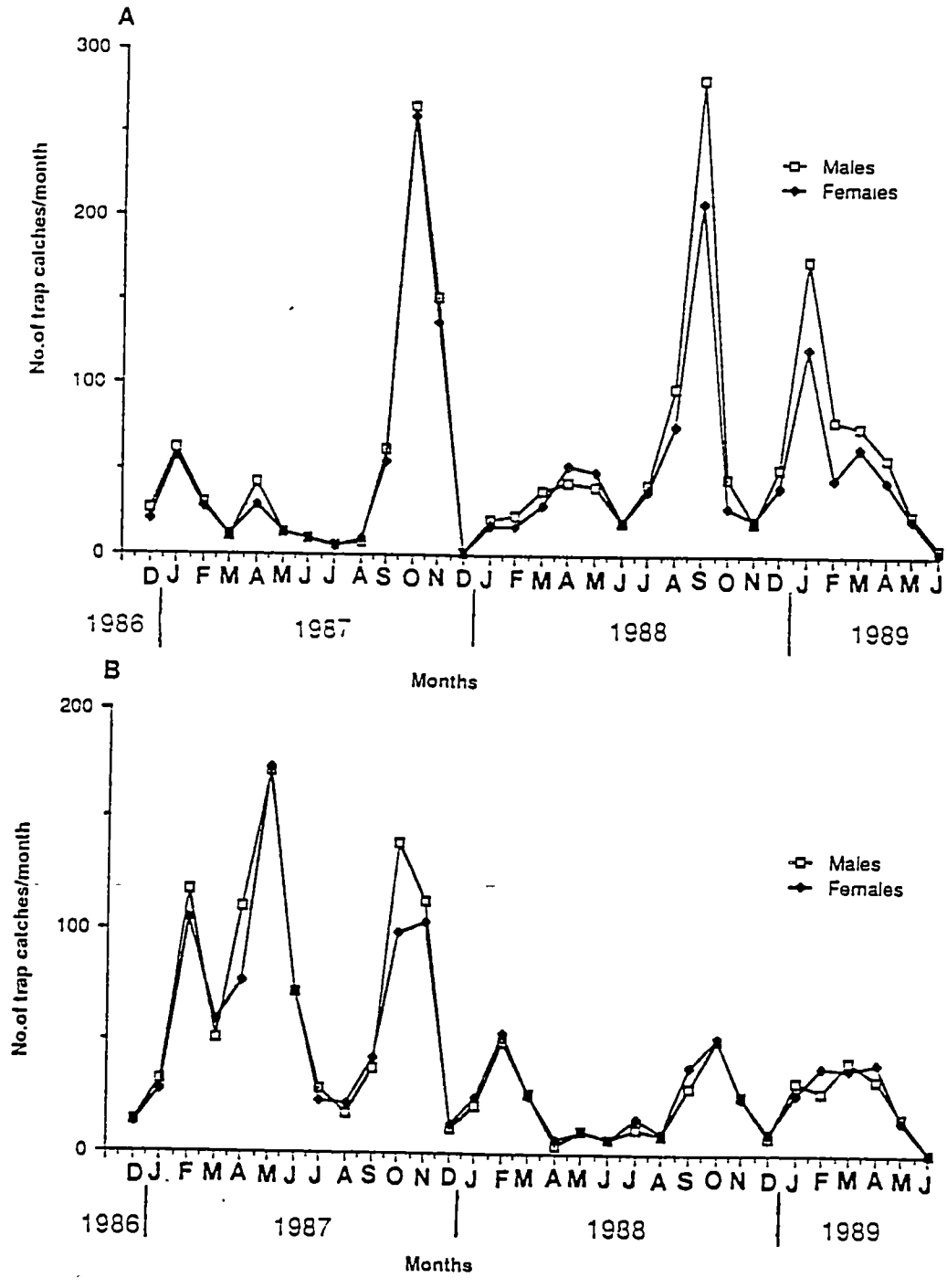


Fig. 24

Mean monthly flight activity of *C.thysanura* adults during the period 1986-1989 in the study areas at (A) Copping, and (B) Kingston.

3.2.3 Adult flight outside the study area

The numbers of *C. thysanura* adults caught on white sticky traps from 1987-1989 were related to the peak number of adults per sweep per bush (Table 24) and also the total number of *C. thysanura* eggs and nymphs per terminal shoot (Table 25).

Table 24

A comparison of the numbers of *C. thysanura* adults caught on white sticky traps placed 100 metres outside the study area with the peak number per 100 boronia bushes at Copping, E.Tasmania 1987-89.

Year	Generation	Adults per 100 bushes	Numbers of adults captured on traps	Total no.of adults on traps / Adults per 100 bushes X 1000
1987	I (Summer)	-	-	-
	II (Autumn/winter)	1824	17	9.32
	III (Spring)	774	69	89.15
1988	I (Summer)	1282	85	66.30
	II (Autumn/winter)	2709	38	14.03
	III (Spring)	1311	1465	1117.47
1989	I (Summer)	639	528	826.29
	II (Autumn/winter)	145	109	751.72

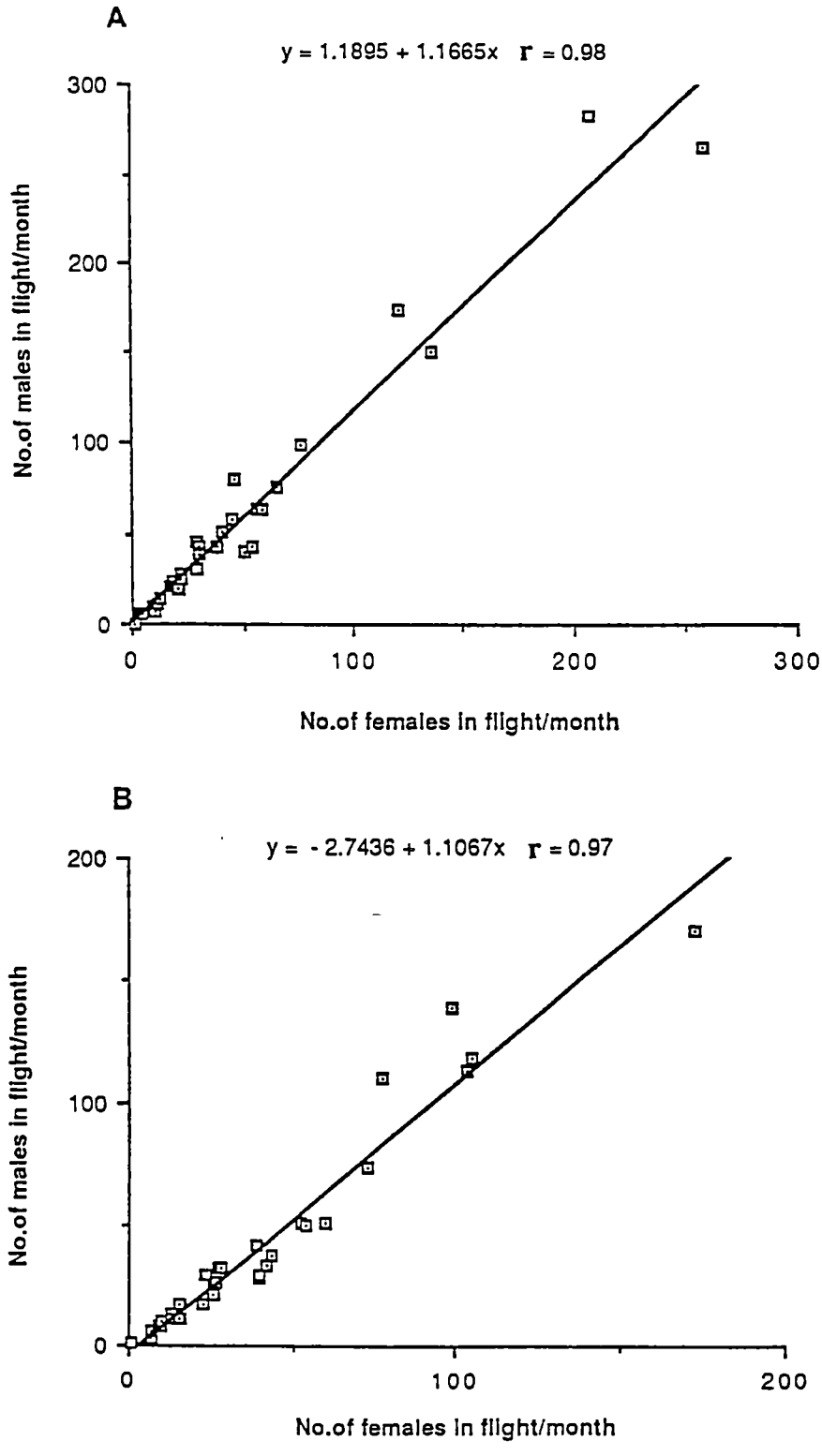


Fig. 25

The relationship between the monthly flight activity of *C.thysanura* adults in the study areas at (A) Copping, (B) Kingston during the period 1986-1989.

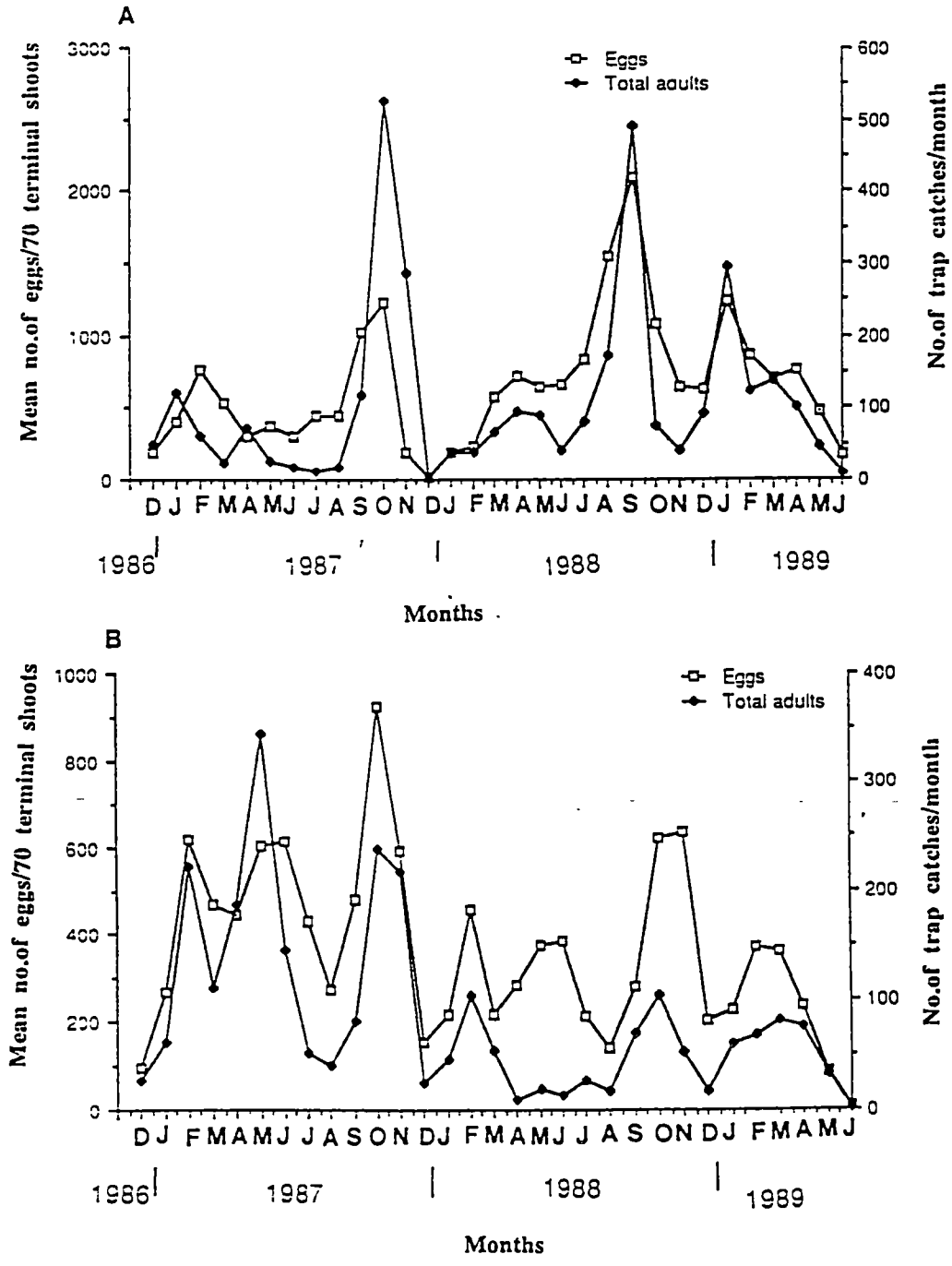


Fig. 26

A comparison of the monthly flight activity of *C.thysanura* adults with the mean number of eggs in the leaf axils of terminal shoots in samples at (A) Copping, and (B) Kingston during the period 1986-1989.

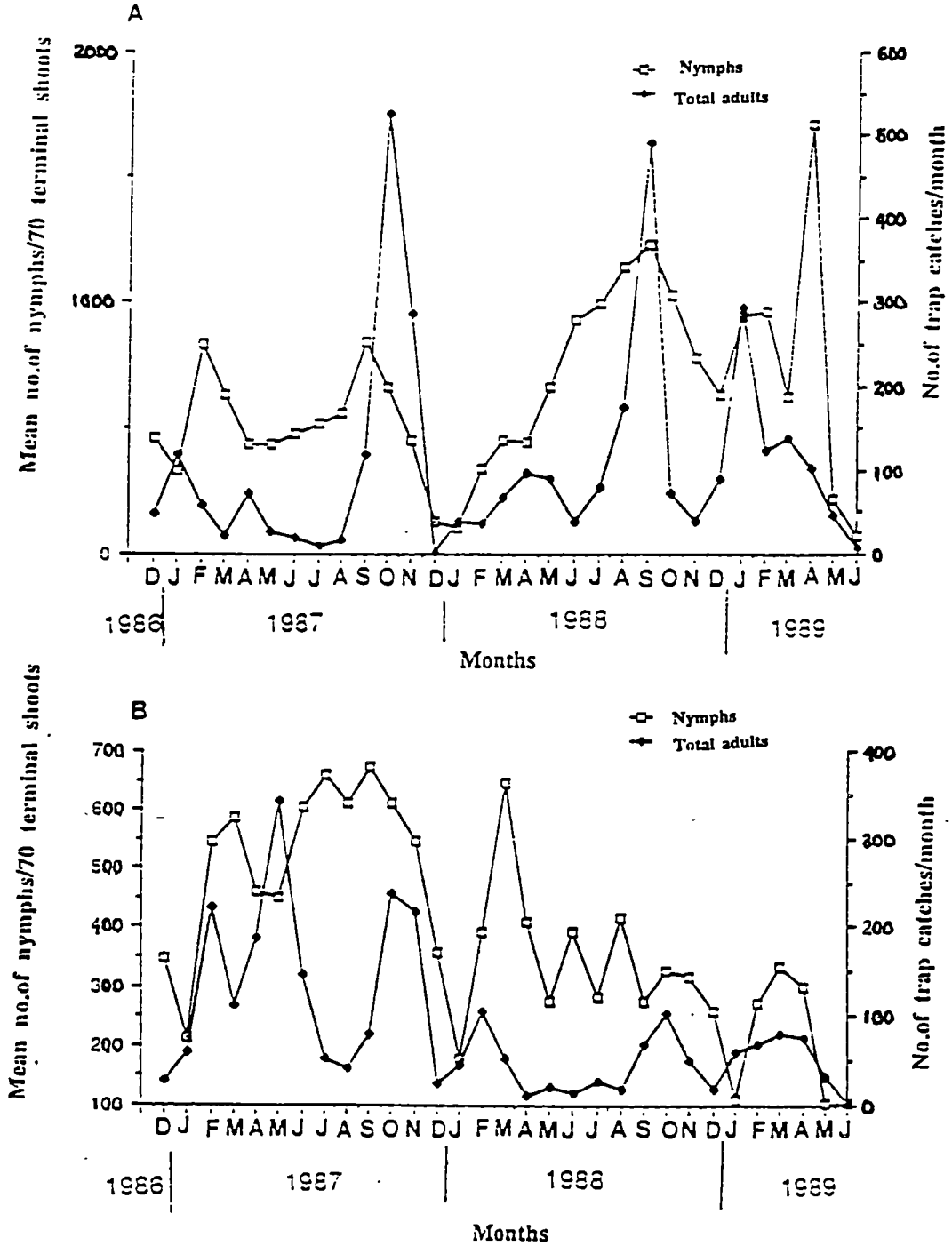


FIG. 27

A comparison of the monthly flight activity of *C.thysanura* adults with the mean number of nymphs in the leaf axils of terminal shoots in samples at (A) Copping, and (B) Kingston during the period 1986-89.

Table 25

A comparison of the numbers of *C.thysanura* adults caught on white sticky traps placed 100 metres outside the study area with the total number of eggs and nymphs per terminal shoot of boronia. (Copping 1987-89).

Year	Generation	No.of eggs and nymphs per terminal shoots.	Total no.of adults caught on white traps	Total no.of adults on traps number of eggs and nymhs per shoot X 1000
1987	I (Summer)	-	-	-
	II(Autumn/winter)	13.37	17	1.27
	III (Spring)	16.46	69	4.19
1988	I (Summer)	10.64	85	7.99
	II(Autumn/winter)	20.04	38	1.90
	III (Spring)	31.67	1465	46.26
1989	I (Summer)	23.48	528	22.49
	II (Autumn/winter)	8.34	109	13.07

The data indicate that emigration occurred in *C. thysanura* in spring but sufferred by low temperature in winter.

3.2.4 Number of generations per season

C. thysanura completed three generations a year at Copping and Kingston. In the other study areas, sampling commenced in the third generation of 1988 and ended in the 1989 (second) generation at Summerleas and Howden and 1989 (first) generation at Bakers Beach and East Sassafras. However, the end of the generations sampled in these latter areas coincided with that at Copping and Kingston, suggesting that *C.*

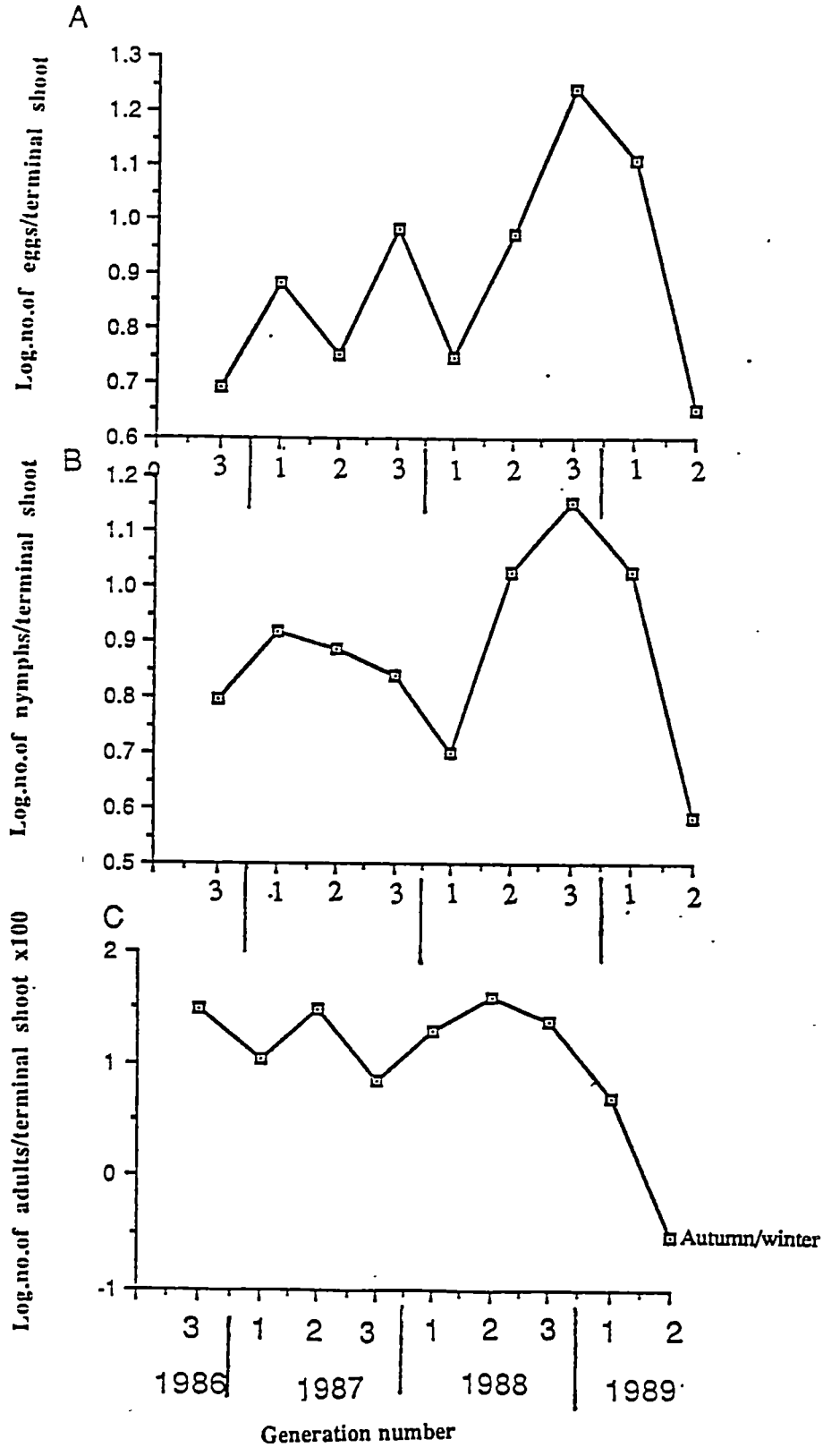


Fig. 28

C.thysanura population changes expressed as generation curves for (A) eggs,(B) nymphal stages, and (C) adults per terminal shoot at Copping,1986-89.

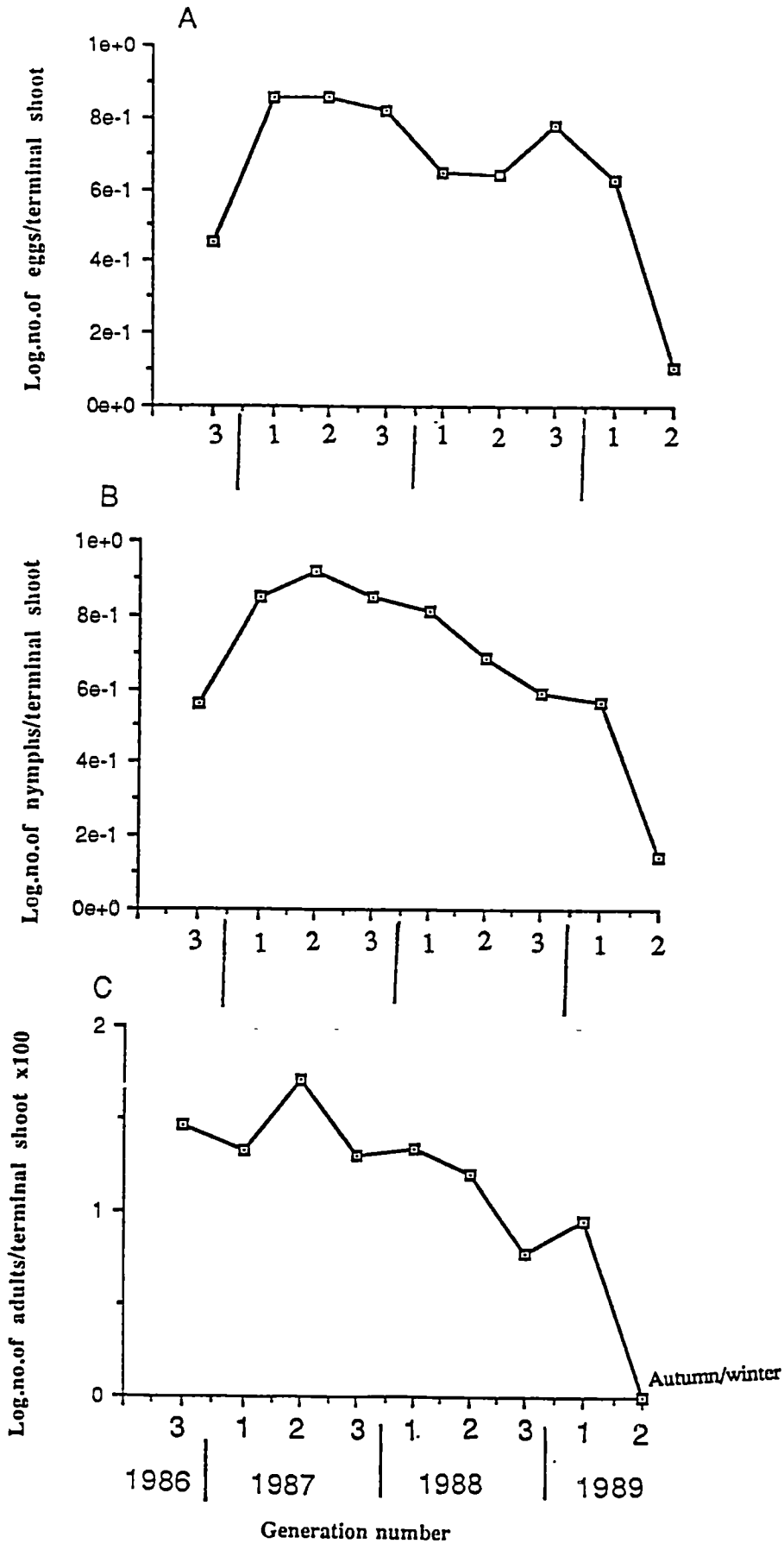


Fig. 29

C.thysanura population changes expressed as generation curves for (A) eggs,(B) nymphal stages, and (C) adults per terminal shoot at Kingston,1986-1989.

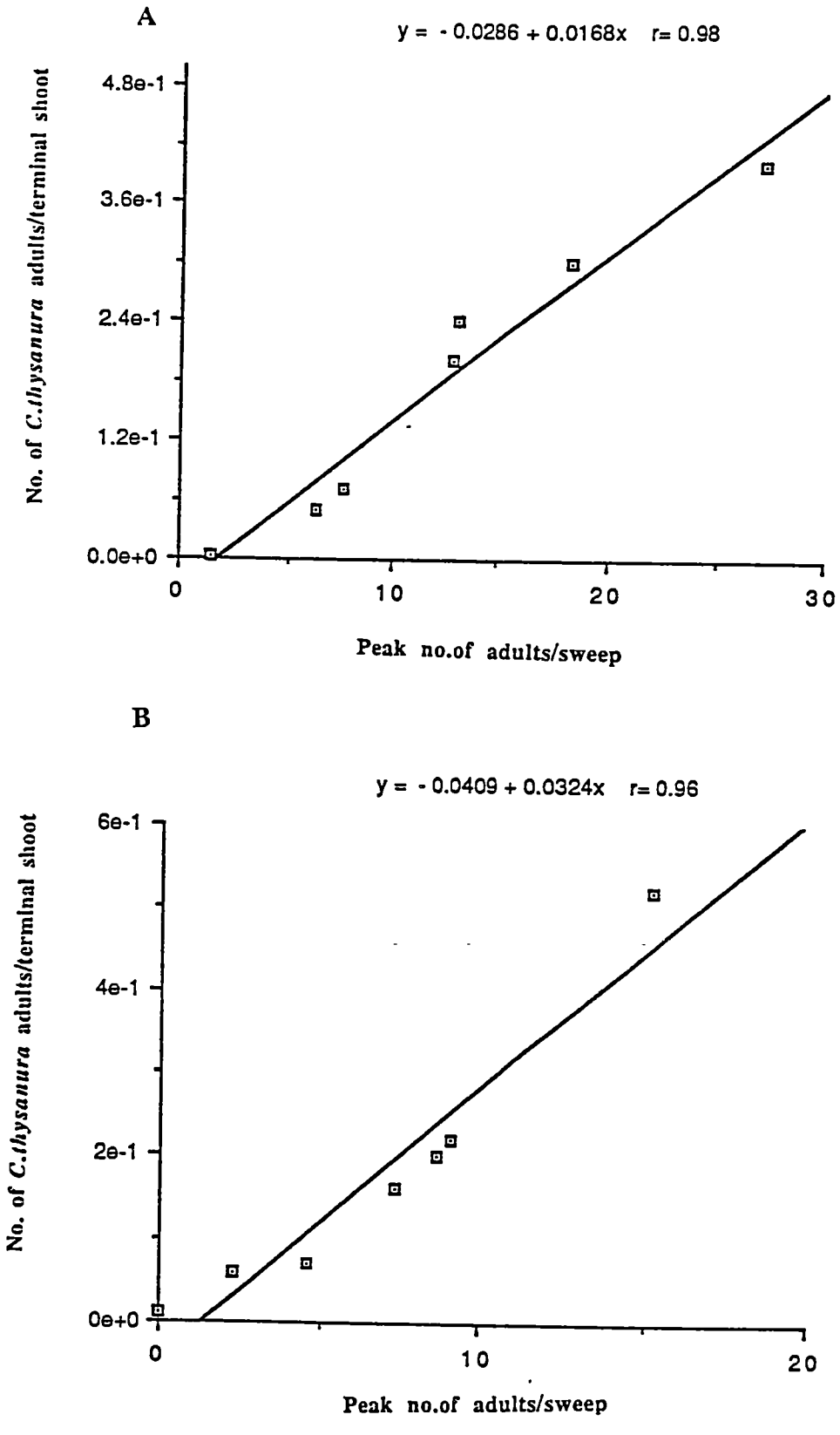


Fig. 30

Relationship between the sweeping net catches of *C.thysanura* adults and the mean number of adults per terminal shoot in samples (of size 70 terminal shoots) at (A) Copping, and (B) Kingston,1987-89. (Results of 6 generations).

thysanura completes three generations in these areas also.

Each generation is represented by a separate egg peak which occurred in the middle of a generation followed by a very low egg number at the end of the generation. The first, second and third generations represent summer, autumn/winter and spring generations.

C. thysanura takes shorter duration to complete a generation in summer and spring, but the autumn/winter generations are longer.

3.3 The description of *C. thysanura* populations at the different study areas

3.3.1 Population changes of *C. thysanura*

The generation curves (expressed on a logarithmic scale) for *C.thysanura* eggs, nymphs and adults based on life table data for Copping and Kingston are shown in Figs. 28 and 29.

At Copping, the peak number of eggs and nymphs were recorded in spring 1988 thereafter, numbers declined, reaching a minimum of 4.50 eggs and 3.93 nymphs per terminal shoot in autumn/winter 1989 (Fig. 28).

The peak numbers of eggs and nymphs at Kingston occurred in autumn/winter 1987, numbers then declined and crashed in winter 1989 (Fig. 29). The dates when maximum egg laying occurred coincided with the period when the boronia plant developed new shoots after pruning and fertilisation in spring. The trend in the buildup and decline of the egg and nymphal population follows the same trend as the adult populations at both Copping and Kingston (Figs. 28 and 29). Sweep net catches of *C. thysanura* commenced at Copping and Kingston in 1987 (autumn/winter generation) (Tables 26 and 27) and the peak number of adults per sweep correlates positively ($P<0.001$) with the number of *C. thysanura* adults per terminal shoot in the samples (Fig. 30).

3.3.2 Mortality in *C. thysanura*

Life tables of *C. thysanura* at Copping (1986/89), Kingston (1986/89) and

Table 26

Life table of *C.thysanura* at Copping,Eastern Tasmania,1986-89 showing the k-values of the successive stages calculated by Varley and Gradwell (1960) method and the percentage mortality between the stages calculated by Richards (1940) method.

Year	Generation	Stage	Total no.of eggs, nymphs and adults per terminal shoot.	k-values	Per cent mortality between successive stages	Peak no.of adults per sweep in the whole study area	Mean no.of eggs and nymphs per terminal shoot in samples
1986	Third (Spring)	Egg	4.92	0.413	-	-	11.18
		I	1.90	0.207	-		
		II	1.18	0.081	37.6		
		III	0.98	-0.070	54.7		
		IV	1.15	0.040	61.1		
		V	1.05	0.421			
		Adult	0.30	-	Total nymphal mortality		
				*kp=0.123			
				K= 1.215	49.9%		
	First (Summer)	Egg	7.61	0.464	-	-	15.88
		I	2.61	0.229	8.3		
		II	1.54	-0.070	47.4		
		III	1.81	0.079	45.4		
		IV	1.51	0.276	66.7		
		V	0.80	0.751			
		Adult	0.11	-	Total nymphal mortality		
				kp=0.111			
				K=1.840	57.1%		
1987	Second (Autumn/winter)	Egg	5.67	0.480	-	18.24	13.37
		I	1.88	0.177	11.4		
		II	1.25	-0.111	42.7		
		III	1.61	-0.041	35.0		
		IV	1.77	0.172	47.6		
		V	1.19	0.514			
		Adult	0.30	-	Total nymphal mortality		
				kp=0.085			
				K=1.276	46.3%		
	Third (Spring)	Egg	9.56	0.540	-	7.74	16.46
		I	2.76	0.317	22.9		
		II	1.33	0.045	63.9		
		III	1.20	0.075	71.3		
		IV	1.01	0.226	82.3		
		V	0.60	0.817			
		Adult	0.07	-	Total nymphal mortality		
				kp=0.198			
				K=2.218	71.5%		

*kp= k-value for parasitism

[TURN TO THE NEXT PAGE FOR THE CONTINUATION OF TABLE 26]

Year	Generation	Stage	Total no.of eggs, nymphs and adults per terminal shoot	k-values	Mortality between successive stages (Per cent)	Peak no.of adults/ sweep in the whole study area	Mean no.of eggs and nymphs per terminal shoot
1988	First (Summer)	Egg	5.61	0.499	-	12.82	10.64
		I	1.78	0.164	15.2		
		II	1.22	0.188	43.5		
		III	0.79	0.127	67.9		
		IV	0.59	-0.042	82.5		
		V	0.65	0.361			
		Adult	0.20	-	Total nymphal mortality		
				kp=0.151			
				K=1.448	56.7%		
	Second (Autumn/winter)	Egg	9.46	0.441	-	27.09	20.04
		I	3.43	0.234	3.0		
		II	2.00	0.002	45.0		
		III	1.99	0.061	51.8		
		IV	1.73	0.083	69.4		
		V	1.43	0.481			
		Adult	0.40	-	Total nymphal mortality		
				kp=0.178			
				K=1.480	55.7%		
	Third (Spring)	Egg	17.52	0.540	-	13.11	31.67
		I	5.06	0.175	22.8		
		II	3.38	0.133	49.9		
		III	2.49	0.146	67.5		
		IV	1.78	0.092	83.0		
		V	1.44	0.692			
		Adult	0.24	-	Total nymphal mortality		
				kp=0.086			
				K=1.864	67.6%		
1989	First (Summer)	Egg	12.91	0.432	-	6.39	23.48
		I	4.77	0.256	1.3		
		II	2.65	0.175	46.4		
		III	1.77	0.279	68.6		
		IV	0.93	0.316	87.8		
		V	0.45	0.681			
		Adult	0.05	-	Total nymphal mortality		
				kp=0.273			
				K=2.412	68.1%		
	Second (Autumn/winter)	Egg	4.50	0.374	-	1.45	8.4
		I	1.93	0.246	6.2		
		II	1.08	0.241	44.2		
		III	0.62	0.491	75.3		
		IV	0.20	0.347	94.0		
		V	0.01	0.824			
		Adult	0.003	-	Total nymphal mortality		
				kp=0.653			
				K=3.176	81.3%		

Summerleas, Howden, Bakers Beach and East Sassafras (1988/89) are given in Tables 26 to 31).

An example of Richards (1940) method used in the calculation of nymphal mortalities at the study areas is given in Table 26.1.

Table 26.1

Calculation of nymphal mortalities for generation 1 at Copping, Tasmania using the method of Richards (1940). Densities expressed as numbers per 70 terminal shoot.

		Numbers of eggs and nymphal stages/70 shoots.					
Rows	Sampling date	Eggs	I	II	III	IV	V
1	24th October 1986	687	208	128	78	53	48
2	3rd Nov.	674	180	143	102	124	57
3	13th Nov	450	127	62	37	40	32
4	23rd Nov.	320	161	71	60	51	31
5	3rd Dec.	282	188	92	80	45	34
6	13th Dec.	233	80	82	96	138	64
7	23rd Dec.	100	60	41	53	122	144
8	5th Jan 1987	7	60	44	42	71	180
9	Total	2753	1064	661	548	644	590
10	Duration of stage (days)	19.4	7.3	7.5	8.5	11.6	14.4
11	Expected number based on stage durations	1767.5	664.0	682.3	775.9	1061.6	1312.7
12	Number expected from 2753 eggs	2753	1034	1063	1209	1654	2045
Loss 9-12		0	+30	-402	-661	-1010	-1455

Row nine in the table gives the total of each stage found by regular 10 day interval sampling during Generation 1. In general, the numbers of each stage found should correspond to the time spent in that stage. Data as to the duration of each stage at average daily mean temperature of 11.14°C at Copping (from 24th October 1986 to 5th January 1987) has been taken from Appendix 7 and form row ten. Row eleven of the table shows the total of 6264 eggs and nymphs divided up into numbers proportional to the duration of each stage. The number of eggs actually found was far more, and fourth and fifth instar nymphs far less than would have been expected. The latter values were most probably due to predation, parasitism and environmental factors and cultural practises such as flower harvesting and pruning at the time when late instar nymphs were abundant. The effect of mature nymphs dispersal within the plant can be eliminated by calculating the numbers of each stage which might have been expected from a random collection of 2753 eggs. These numbers are shown in row twelve of the table. The discrepancy between the numbers of first-, second-, third-, fourth- and fifth instar nymphs in rows nine and twelve gives a measure of the mortality.

Nymphal mortality was very low in egg (0) and first (+30) and progressively increased from second to fifth nymphal stages.

Chi square analysis of the total egg and nymphal mortality K (using K values at Copping as the expected mortality and the K values at each of the study areas as observed mortality) did not differ significantly ($P_X2>0.05$) between generations, indicating that mortalities at each locality were similar. Total egg and nymphal 'K' mortality in 1986/88 at Copping was highest in the spring generation (2.218) followed by the summer generation (1.840) with the autumn/winter generation recording the lowest (1.276). *C. thysanura* mortality was higher during the 1989 season causing the population to collapse in the autumn/winter generation.

The results indicate that the mortalities calculated using Richards' (1940) method compare very well with the total generation mortality, K, at all study sites. The equation for the relationship at Copping was $y=30.2017+16.6805x$; $r^2=0.8836$; and at Kingston $y=25.7393+23.3954x$; $r^2=0.9025$; where y = total nymphal mortality calculated using Richards (1940) method, and x= total generation mortality (K) derived by the Varley and Gradwell (1968) method.

Table 27

Life table of *C.thysanura* at Kingston,Southern Tasmania,1986-89 showing the k-values of successive stages calculated by Varley and Gradwell (1960) method and the percentage mortality between the stages calculated by Richards (1940) method.

Year	Generation	Stage	Total no.of eggs, nymphs and adults per terminal shoot in samples	k-values	Per cent mortality between successive stages	Peak no.of adults per sweep in the whole study area	Mean no.of eggs and nymphs per terminal shoot in samples.
		Egg	2.82	0.472			
					-		
		I	0.95	0.270			
					9.6		
		II	0.51	-0.032			
					52.6		
1986	Third	III	0.55	-0.052		-	6.45
					55.2		
	(Spring)	IV	0.62	-0.028			
					63.4		
		V	1.00	0.407			
		Adult	0.29	-	Total nymphal		
				*kp=0.131	mortality		
				K=0.988	49.1%		
		Egg	7.20	0.545			
					-		
		I	2.05	0.247			
					23.6		
		II	1.16	-0.065			
					58.0		
	First	III	1.35	-0.034		-	14.27
					57.1		
	(Summer)	IV	1.46	0.143			
					66.1		
		V	1.05	0.434			
		Adult	0.21	-	Total nymphal		
				kp=0.150	mortality		
				K=1.420	61.2%		
		Egg	7.13	0.464			
					-		
		I	2.45	0.538			
					8.2		
		II	0.71	-0.298			
					77.8		
1987	Second	III	1.41	-0.161		15.24	15.30
					54.6		
(Autumn/winter)		IV	2.04	0.090			
					52.1		
		V	1.66	0.398			
		Adult	0.52	-	Total nymphal		
				kp=0.106	mortality		
				K=1.137	54.8%		
		Egg	6.58	0.483			
					-		
		I	2.16	0.205			
					12.3		
		II	1.35	-0.028			
					46.7		
	Third	III	1.44	0.031		8.62	13.67
					49.9		
	(Spring)	IV	1.34	0.224			
					65.9		
		V	0.80	0.462			
		Adult	0.20	-	Total nymphal		
				kp=0.140	mortality		
				K=1.517	57.4%		

*kp= k-value for parasitism

[TURN TO THE NEXT PAGE FOR THE CONTINUATION OF TABLE 27]

Year	Generation	Stage	Total no.of eggs, nymphs and adults per terminal shoot	k-values	Mortality between successive stages (Per cent)	Peak no.of adults per sweep in the whole study area	Mean no.of eggs and nymphs per terminal shoot
		Egg	4.44	0.350			
					-		
		I	1.98	0.104			
					-		
		II	1.56	0.111			
					8.4		
	First	III	1.21	0.118		9.09	10.92
					37.5		
	(Summer)	IV	0.92	0.055			
					65.4		
		V	0.81	0.414			
		Adult	0.16	-	Total nymphal		
				kp=0.153	mortality		
				K=1.305	55.9%		
		Egg	4.35	0.466			
					-		
		I	1.49	0.156			
					8.4		
		II	1.04	0.068			
					37.8		
1988	Second	III	0.89	0.068		7.33	9.18
					53.2		
	(Autumn/winter)	IV	0.76	0.068			
					70.9		
		V	0.65	0.458			
		Adult	0.16	-	Total nymphal		
				kp=0.150	mortality		
				K=1.435	56.2%		
		Egg	6.00	0.593			
					-		
		I	1.53	0.198			
					31.9		
		II	0.97	0.202			
					58.2		
	Third	III	0.61	0.113		2.18	9.92
					76.8		-
	(Spring)	IV	0.47	0.140			
					87.0		
		V	0.34	0.477			
		Adult	0.06	-	Total nymphal		
				kp=0.277	mortality		
				K=2.00	74.3%		
		Egg	4.25	0.473			
					-		
		I	1.43	0.252			
					9.9		
		II	0.80	0.179			
					51.4		
	First	III	0.53	0.016		4.56	7.96
					71.3		
	(Summer)	IV	0.51	0.064			
					79.7		
		V	0.44	0.444			
		Adult	0.09	-	Total nymphal		
				kp=0.246	mortality		
				K=1.674	65.5%		
		Egg	1.28	0.336			
					-		
		I	0.59	0.090			
					-		
		II	0.48	0.283			
					-		
1989	Second	III	0.25	0.620		0.03	2.66
					15.5		
	(Autumn/winter)	IV	0.06	0.778			
					84.6		
		V	0.01	0.000			
		Adult	0.01	-			
				K=2.107			

Table 28

Life table of *C.thysanura* at Summerleas,Southern Tasmania,1988-89 showing the k-values of the successive stages calculated by Varley and Gradwell (1960) method and the percentage mortality between the stages calculated by Richards (1940) method.

Year	Generation	Stage	Total no.of eggs,nymphs and adults per terminal shoot in samples.	k-values	Per cent mortality between successive stages	Peak no.of adults per sweep in the whole study area.	Mean no.of eggs and nymphs per terminal shoot in in samples.
1986	Third	Egg	7.66	0.594	-	45.36	12.46
		I	1.95	0.341	31.9		
		II	0.89	0.092	69.8		
		III	0.72	0.072	78.5		
		IV	0.61	-0.140	86.7		
		V	0.63	0.803			
		Adult	0.070	-	Total nymphal		
				kp=0.151	mortality		
				K=1.913	72.3%		
1989	First	Egg	12.11	0.505	-	43.22	20.62
		I	3.78	0.390	16.5		
		II	1.54	0.054	67.0		
		III	1.36	0.113	74.3		
		IV	1.05	0.129	85.5		
		V	0.78	0.887			
		Adult	0.068	-	Total nymphal		
				kp=0.172	mortality		
				K=2.25	75.3%		
	Second	Egg	3.92	0.712	-	0.70	5.99
		I	0.76	0.337	48.3		
		II	0.35	-0.146	76.8		
		III	0.49	-0.185	71.7		
		IV	0.32	0.727	86.3		
		V	0.15	0.681			
		Adult	0.015	-	Total nymphal		
				kp=0.319	mortality		
				K=2.496	80.1%		

Table 29

Life table of *C.thysanura* at Howden,Southern Tasmania,1988-89 showing the k-values of the successive stages calculated by Varley and Gradwell (1960) method and the percentage mortality between the stages calculated by Richards (1940) method.

Year	Generation	Stage	Total no.of eggs and adultsper terminal shoot in samples.	k-values	Per cent mortality between successive stages	Peak no.of adults per sweep in the whole study area.	Mean no.of eggs and nymphs per terminal shoot in samples.
1988	Third	Egg	16.61	0.722	-	4.88	24.15
		I	3.15	0.090	49.3		
		II	2.56	0.399	59.8		
		III	1.02	0.231	86.0		
		IV	0.60	0.456	94.0		
		V	0.21	0.895	-		
		Adult	0.014	-	Total nymphal		
				kp=0.281	mortalitry		
				K=3.074	82.1%		
1989	First	Egg	2.94	0.486	-	5.16	6.13
		I	0.96	0.101	12.9		
		II	0.76	0.012	32.3		
		III	0.74	0.179	42.2		
		IV	0.49	0.310	72.3		
		V	0.24	0.602			
		Adult	0.030	-	Total nymphal		
				kp=0.301	mortality		
				K=1.991	57.1%		
	Second	Egg	1.86	0.401	-	0.76	3.75
		I	0.74	0.098	-		
		II	0.59	0.294	17.0		
		III	0.30	0.222	63.0		
		IV	0.18	0.301	83.9		
		V	0.09	0.477			
		Adult	0.010	-	Total nymphal		
				kp=0.477	mortality		
				K=2.270	60.1%		

Table 30

Life table of *C.thysanura* at Bakers Beach N.W.Tasmania,1988-89 showing the k-values of the successive stages calculated by Varley and Gradwell (1960) method and the percentage mortality between the stages calculated by Richards (1940) method.

Year	Generation	Stage	Total no.of eggs, nymphs and adults per terminal shoot in samples	k-values	Per cent mortality between successive stages	Peak no.of adults per sweep in the whole study area	Mean no.of eggs and nymphs per terminal shoot in samples
		Egg	20.75	0.657	-		
		I	4.57	0.344	41.1		
		II	2.07	0.068	74.1		
1988	Third	III	1.77	-0.015	80.5	13.64	32.19
		IV	1.83	0.180	85.2		
		V	1.21	0.935			
		Adult	0.10	-	Total nymphal		
				kp=0.148	mortality		
				K=2.317	78.2%		
		Egg	9.28	0.366	-		
		I	4.00	0.310	-		
		II	1.96	0.202	45.2		
1989	First	III	1.23	0.215	69.7	2.94	17.70
		IV	0.75	0.194	86.5		
		V	0.48	0.699			
		Adult	0.060	-	Total nymphal		
				kp=0.204	mortality		
				K=2.190	64.2%		

Table 31

Life table of *C.thysanura* at East Sassafras,N.W.Tasmania,1988-89,showing the k-values of the successive stages calculated by Varley and Gradwell (1960) method.

Year	Generation	Stage	Total no.of eggs,nymphs and adults per terminal shoot in samples.	k-values	Per cent mortality between successive stages.	Peak no.of adults per sweep in the whole study area. samples.	Mean no.of eggs and nymphs per terminal shoot in
		Egg	24.01	0.351	-		
		I	10.70	0.138	-		
		II	7.78	0.164	15.6		
1988	Third	III	5.33	0.002	49.9	23.28	57.17
		IV	5.31	0.119	63.0		
		V	4.04	0.543			
		Adult	0.92	-	Total nymphal		
				kp=0.099	mortality		
				K=1.416	45.4%		
		Egg	7.66	0.382	-		
		I	3.18	0.188	-		
		II	2.06	0.174	30.1		
1989	First	III	1.38	0.111	58.7	2.72	15.83
		IV	1.07	0.348	76.6		
		V	0.48	0.903			
		Adult	0.03	-	Total nymphal		
				kp=0.301	mortality		
				K=2.407	59.1%		

Adult-egg ratios were calculated and are shown in Tables 32 to 34. These results agree closely with the estimated figures of total egg and nymphal mortality (K). The data indicate a lower adult to egg ratio at higher egg plus nymphal mortalities and vice versa.

Table 32

Total egg and nymphal mortality expressed as K-values calculated by Varley and Gradwell (1960) method compared with the egg-adult ratios for *C.thysanura* at Copping,1986-89.

Year	Generation	Total egg and nymphal mortality expressed as K-values	Number of adults per shoot / Number of eggs per shoot X 1000
1986	Third (Spring)	1.215	61
1987	First (Summer)	1.840	15
	Second(Autumn/winter)	1.276	53
	Third (Spring)	2.218	7
1988	First (Summer)	1.448	36
	Second(Autumn/winter)	1.480	42
	Third (Spring)	1.864	14
1989	First (Summer)	2.412	4
	Second(Autumn/winter)	3.176	1

3.3.3 The causes of *C.thysanura* population change or the recognition of the key mortality factors.

Figs. 31 and 32 show the graphical key factor analyses of the life table data for *C.thysanura* (Tables 26 and 27) at Copping and Kingston according to the method of Varley and Gradwell (1968). The different mortality factors acting on successive stages of *C.thysanura* have been expressed as k-values and plotted against the generation number. The k-values (viz., k_e, k_1, k_2, k_3, k_4, k_5, k_p) are the mortalities for eggs and the first, second, third, fourth and fifth nymphal stages, respectively and k_p is the mortality due to parasitism. The total generation mortality, $K = k_e + k_1 + k_2 + k_3 + k_4 + k_5 + k_p$.

The total generation mortality, K, single and combined k-values were plotted against the generation number (Fig. 31 for Copping and Fig. 32 for Kingston) to show the variation in each k-value and of the total K during the study period.

Table 33

Total egg and nymphal mortality expressed as K-values calculated by Varley and Gradwell (1960) method compared with the egg-adult ratios for *C.thysanura* at Kingston,1986-89.

Year	Generation	Total egg and nymphal mortality expressed as	Number of adults per shoot / Number of eggs per shoot X1000
1986	Third (Spring)	0.988	103
	First (Summer)	1.535	29
1987	Second(Autumn/winter)	1.137	73
	Third (Spring)	1.517	30
	First (Summer)	1.305	50
1988	Second(Autumn/winter)	1.435	37
	Third (Spring)	2.000	10
1989	First (Summer)	1.674	21
	Second (Autumn/winter)	0	-

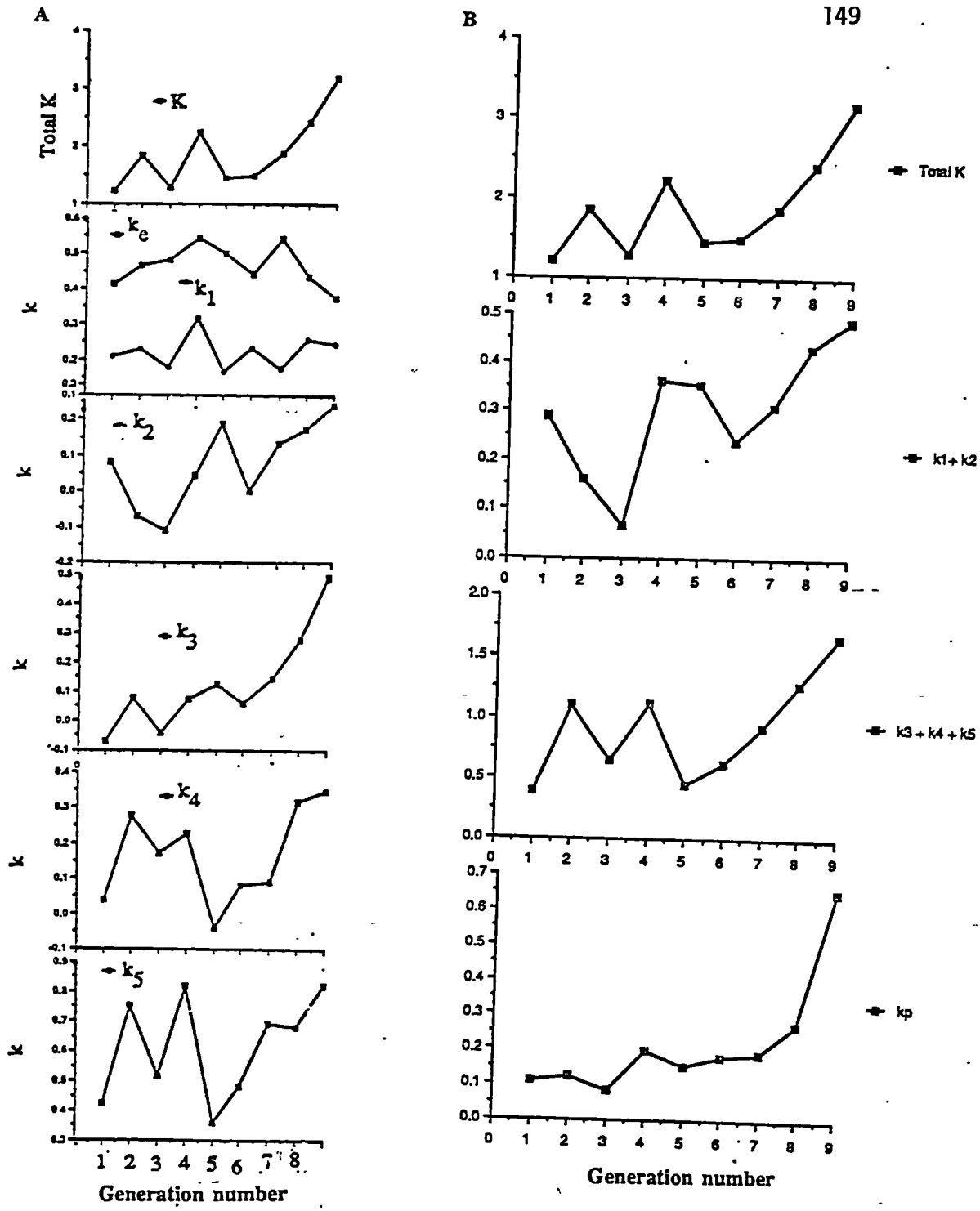


Fig. 31.

Graphical single (A) and combined (B) key factor trends of mortalities affecting *C.thysanura* populations at Copping, 1986-89.

K=Total generation; k_e= egg; k_1=1st instar; k_2=2nd instar; k_3=3rd instar; k_4=4th instar; k_5=5th instar mortalities and k_p=mortalies due to parasitism.

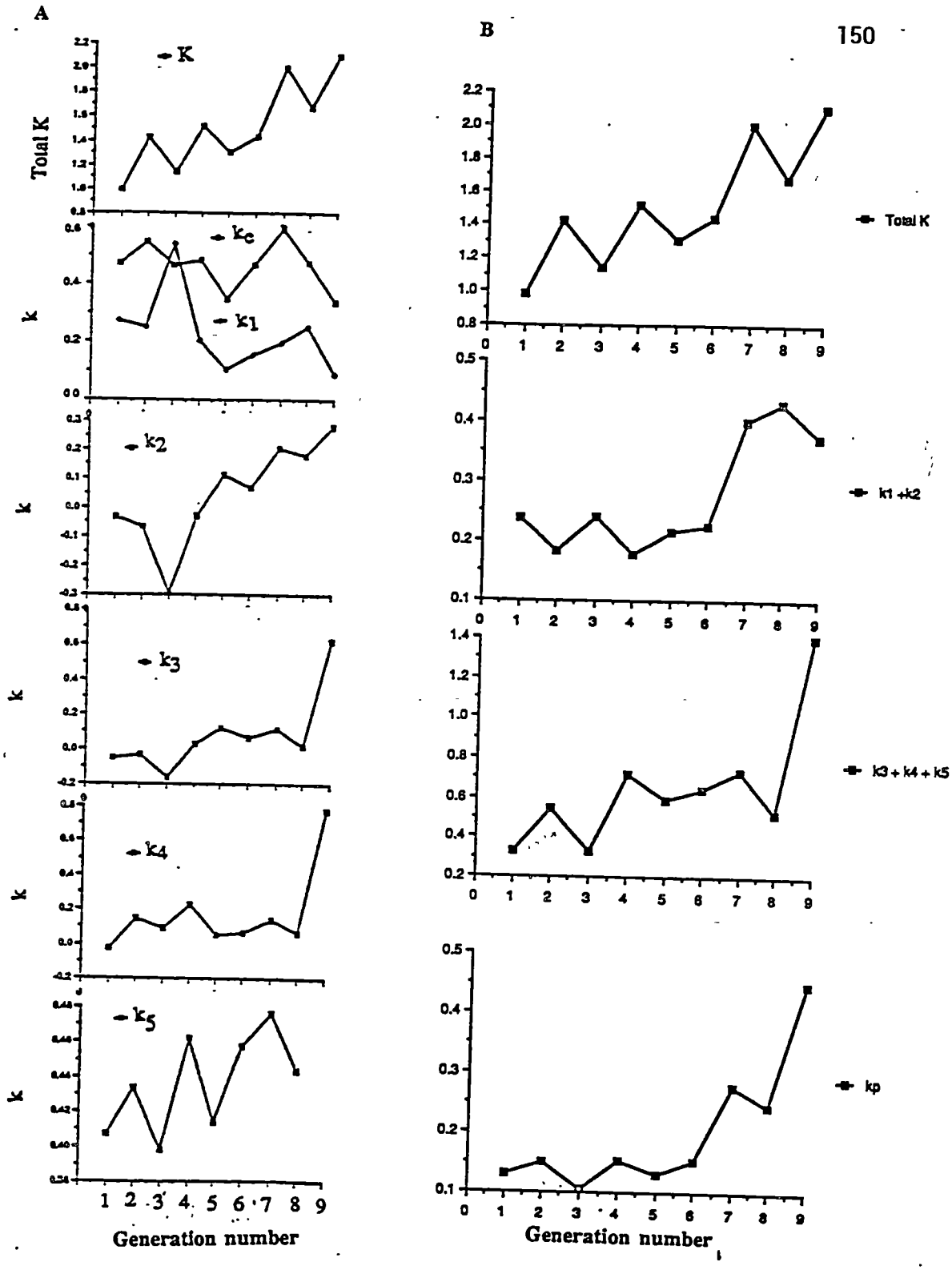


Fig. 32

Graphical single (A) and combined (B) key factor trends of mortalities affecting *C.thysanura* populations at Kingston, 1986-89.

K=Total generation; k_e=egg; k_1=1st instar; k_2=2nd instar; k_3=3rd instar; k_4 =4th instar; k_5 =5th instar mortalities and k_p =mortalities due to parasitism.

Table 34

Total egg and nymphal mortality expressed as K-values calculated by Varley and Gradwell (1960) method compared with the egg-adult ratios for *C.thysanura* at (A) Summerleas, (B) Howden, (C) East Sassafras and (D) Bakers Beach,1988-89.

Year	Generation	Total egg and nymphal mortality expressed as K-values.	Number of adults per shoot / Number of eggs per shoot X 1000
(A) Summerleas:			
1988	Third (Spring)	1.913	9
1989	First (Summer)	2.250	6
	Second (Autumn/winter)	2.496	4
(B) Howden:			
1988	Third (Spring)	3.074	1
1989	First (Summer)	1.991	10
	Second (Autumn/winter)	2.270	5
(C) East Sassafras:			
1988	Third (Spring)	1.416	38
1989	First (Summer)	2.407	4
(D) Bakers Beach:			
1988	Third (Spring)	2.317	5
1989	First (Summer)	2.190	7

At Copping, the form of the lines for single and combined k_3, k_4 and k_5 and also k_p are very similar to that of the total K in both the amount and direction of change, which indicates that the mortality of the third, fourth and fifth nymphal instar is the key

mortality factor (Fig. 31).

The form of the lines for single and combined k_3, k_4 and k_5 and also k_p at Kingston are very similar to K, in both amount and direction of change, indicating that k_3, k_4 and k_5 are the key mortality factors (Fig. 32).

The mortalities, k_e, single and combined $k_1$and k_2 do not change in the same direction as K and so these mortality factors are not regarded as the key factors causing changes in the *C. thysanura* population. The changes in k_e, single and combined k_1 and k_2 at some generations occur in ways opposite to the changes in single and combined k_3, k_4 and k_5, so that changes in K in some *C. thysanura* generations are less than changes in k_3, k_4 and k_5, indicating that they tend to compensate for changes brought about by k_3, k_4 and k_5. The k_5 value at Kingston (Fig. 32) during the second generation is missing because the population crashed before the fifth nymphal instar was reached. The higher mortality in the fourth nymphal instar led to the population crash, but it is evident in Fig. 32 that the k_5 value could have been higher, looking at the trend of the k_5 graph

3.3.4 The causes of population regulation

The tests for density relationships are shown in Figs 33 and 34. The k-values are plotted against the logarithms of the populations upon which they acted. The slopes of the resulting curves were tested against b=0. The slope of the regression line for k_e differs significantly ($P<0.20$ and $P<0.05$ at Copping and Kingston, respectively) from b=0 and it is positive, indicating direct density dependent mortality factors. A similar relationship was obtained when k_e was plotted against Nt; the numbers of eggs at the beginning of the period.

The slope of the regression line for k_1 at the two study areas differs significantly ($P<0.10$ and $P<0.50$) from b=0, again indicating direct density dependence.

The slope of the regression line for k_2 does not differ significantly ($P>0.50$) from b=0, but the temporal sequence of points suggested delayed density independence.

The slopes of the regression lines for k_3, k_4 and k_5 at both study areas differ significantly from b=0, are negative, suggesting factors acting in an inverse density dependent manner. When the individual points on k_1, k_2, k_3, k_4 and k_5 for each

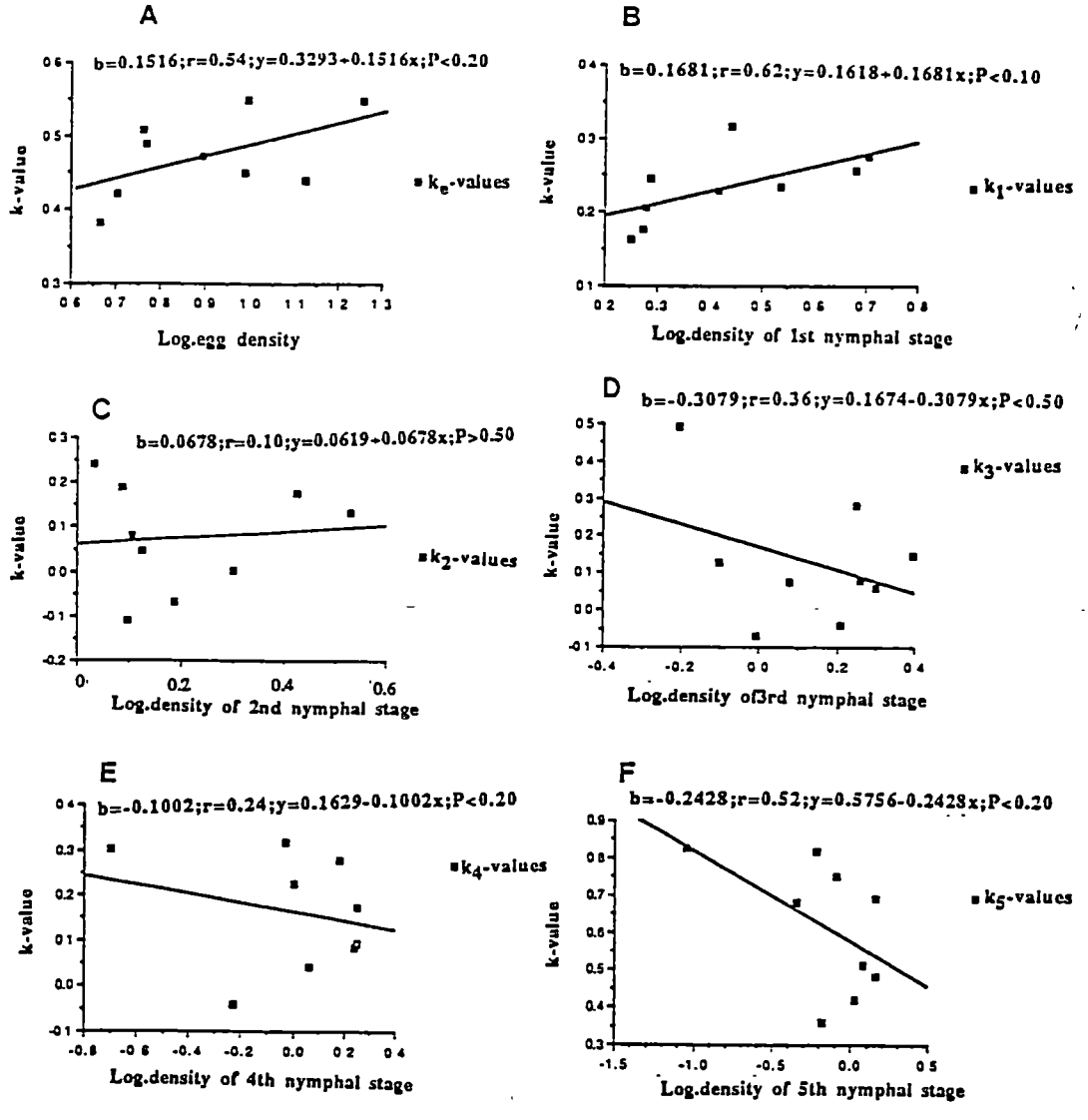


Fig. 33

Test for density relationships: plot of k-values against the log density on which they act (Varley and Gradwell ,1968) in the study area at Copping, 1986-89. (Data from Table 26).

The slopes of the curves in "A,B,D,E,and F" are significantly different from a slope of b=0; but in "C" the slope of the curve is not significantly different from a slope of b=0, indicating density independence.

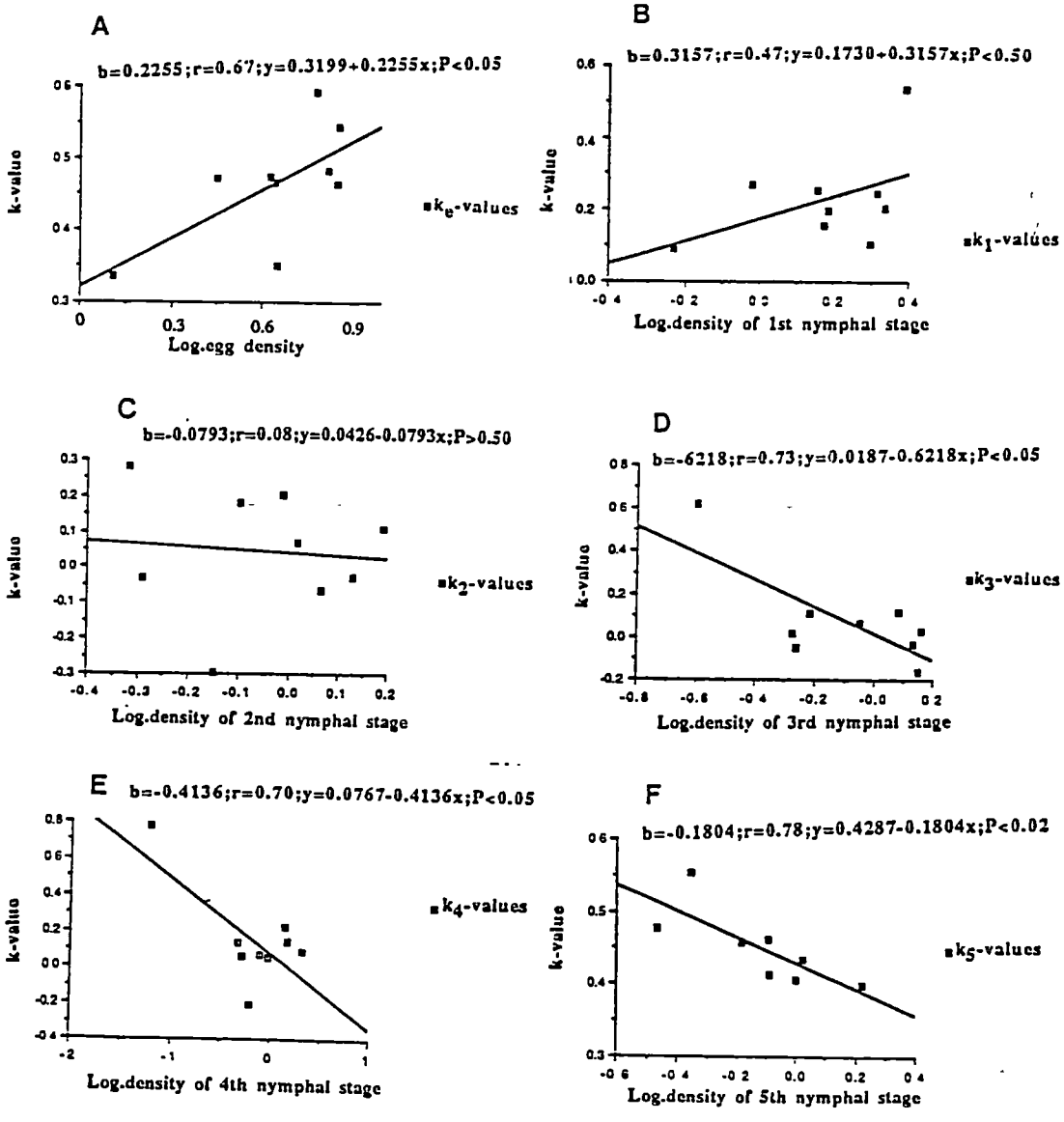


Fig. 34

Test for density relationships; plot of k-values against the log density on which they act (Varley and Gradwell,1968) in the study area at Kingston,1986-89. (Data from Table 27).

The slopes of the curves in "A,B,D,E,and F" are significantly different from a slope of b=0; but the slope of the curve in "C" is not significantly different from b=0,indicating density independence.

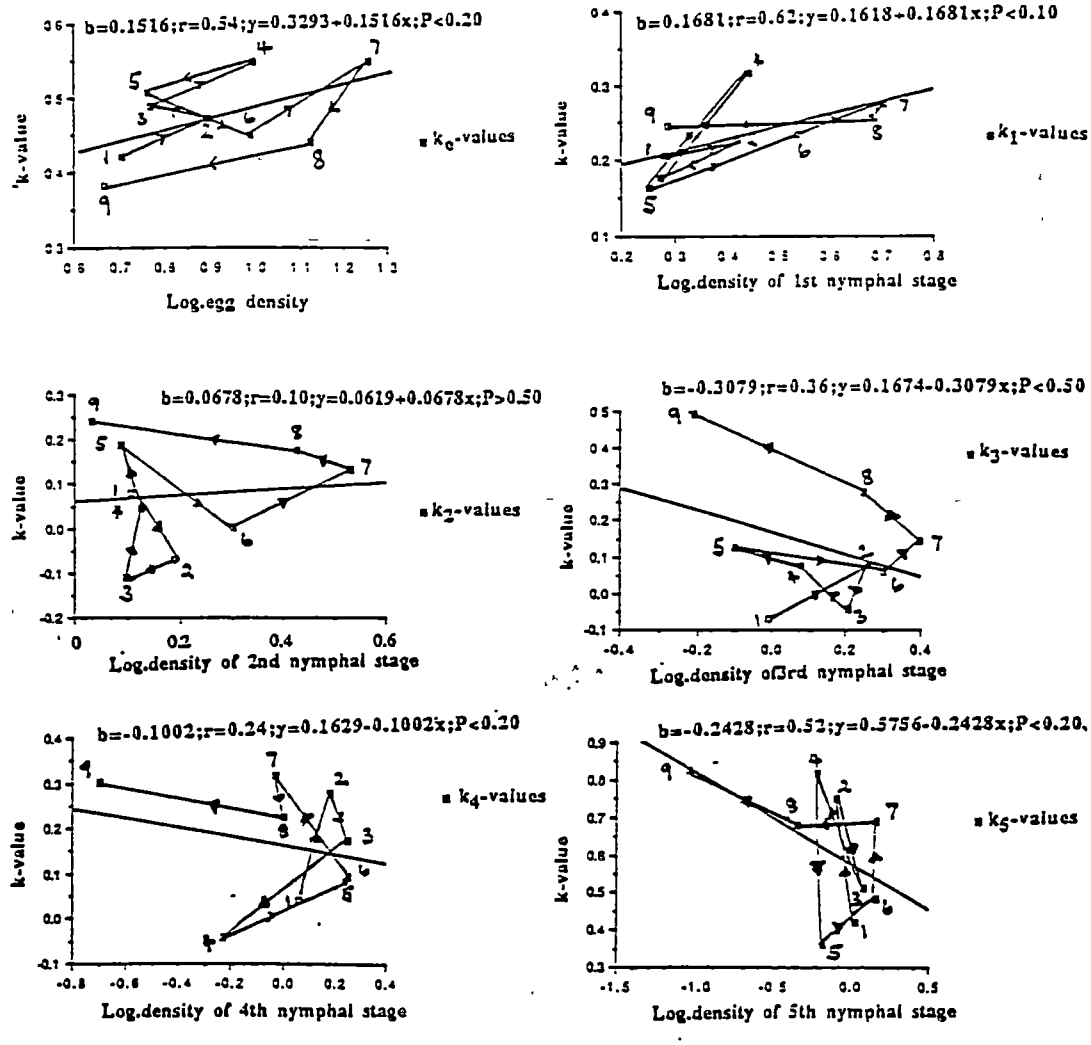


Fig.35

The k-values for the egg, 1st, 2nd, 3rd, 4th and 5th nymphal stages of *C.thysanura* plotted against the log densities upon which they act, with the points joined in a time series in the study area at Copping, 1986-89.

The number 1 represents the 3rd generation of 1986; 2-4 the 1st to 3rd generations of 1987; 5-7 the 1st to 3rd generations of 1988; and 8-9 the 1st and 2nd generations of 1989.

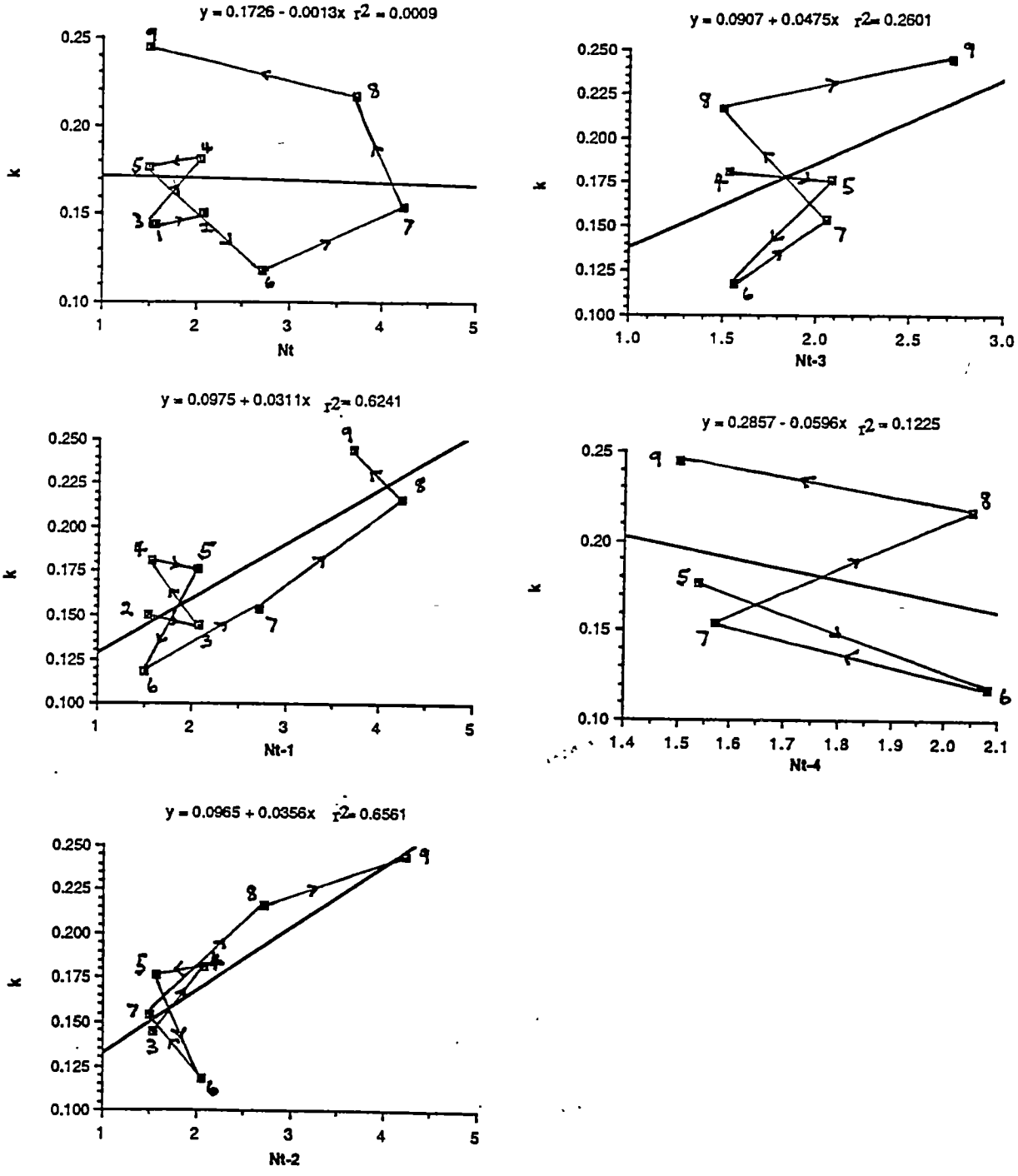


Fig.35.1

Plot of k value on N_t, N_{t-1}, N_{t-2}, N_{t-3} and N_{t-4} where N_t is the combined number of 1st and 2nd instar nymphs in generation *t* at Copping, 1986-89.

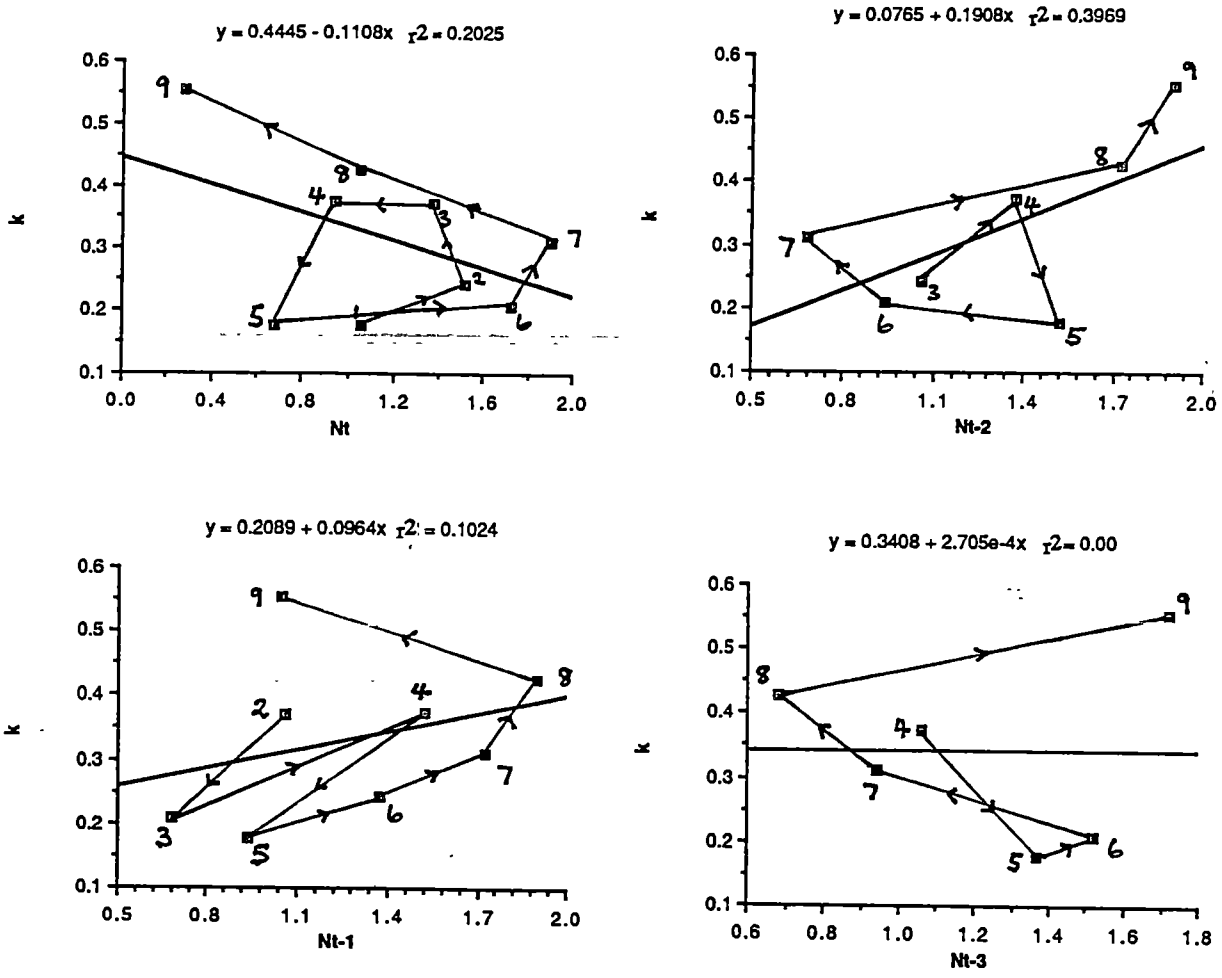


Fig.35.2

Plot of k value on N_t, N_{t-1}, N_{t-2} and N_{t-3}, where N_t is the combined number of 3rd, 4th and 5th instar nymphs in generation *t* at Copping, 1986-89.

generation are linked serially, they indicate some elements of a delayed density dependent mortality factor (Figs 35 and 36).

The above indications were tested for delayed density dependence by calculating the k values for the combined (i) first and second and (ii) third to fifth stage nymphs and plotted against N_t, N_{t-1}, N_{t-2}, etc, where N_t = initial density of first and third stage nymphs respectively in the t th generation. (Figs. 35.1, 35.2, and 36.1) The rationale for combination of stage was that the first two nymphal stages experience both predation by coccinellid larvae and spiders and parasitism by a microhymenopteran complex while the deaths due to parasitism occur during the third to fifth stages.

At Copping, the intrageneration plots clearly indicate delayed density dependence (Figs. 35.1 and 35.2). Plots of k_t versus N_t, N_{t-1} and N_{t-2} revealed increased density related change with r^2 values changing from zero to 0.62 and 0.66 respectively at t, t-1, t-2 for the early stages (Fig.35.1) and, less pronounced changes from 0.20 with negative slope to 0.10 and 0.40 (and positive slope) for late stage nymphs (Fig.35.2). At N_{t-4} for early stages, r^2 had fallen to 0.12 and for late stages r^2 was zero at N_{t-3}.

These results indicate that a negative density dependent feedback mechanism acts upon (a) the first and second stages which has a delay of three generations and (b) the third to fifth stages with a delay of two generations.

Plots of coccinellids and spiders against psyllid stages (Figs.39 to 42) indicated that spiders were the most effective predators being always associated with their prey. In contrast coccinellids appeared only in early spring and summer. Similarly, a syrphid predator only occurred during spring.

These relationships also existed at Kingston but were less pronounced for an ill timed oil spray followed by monocrotophos foliage spray for control of scale insects during the fifth and sixth generations seriously affected enemy - host relationships and in particular the density dependent action of spiders and parasitoids (Fig.36.1).

Varley and Gradwell (1968) considered that plotting the initial density on which the k-value acted against the log density of the surviving population and vice versa (Figs 37 and 38) and each of the two regression slopes tested against b=1, provided a test for density dependence. This test has been critized on the basis that true independence of Y variate values does not exist and therefore invalidates the test on

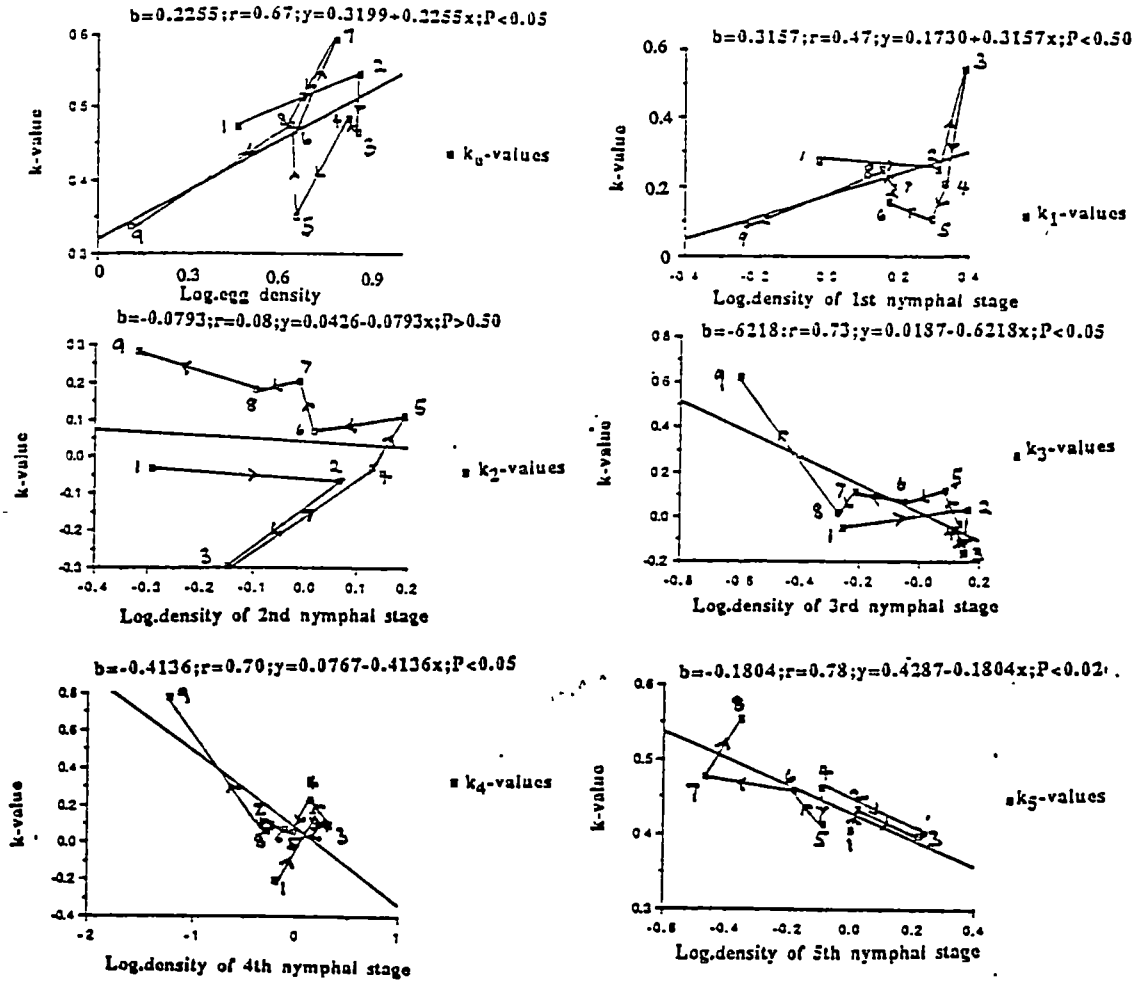


Fig. 36

The k-values for the egg,1st,2nd,3rd,4th and 5th nymphal stages of *C.thysanura* plotted against the log densities upon which they act, with the points joined in a time series in the study area at Kingston, 1986-89.

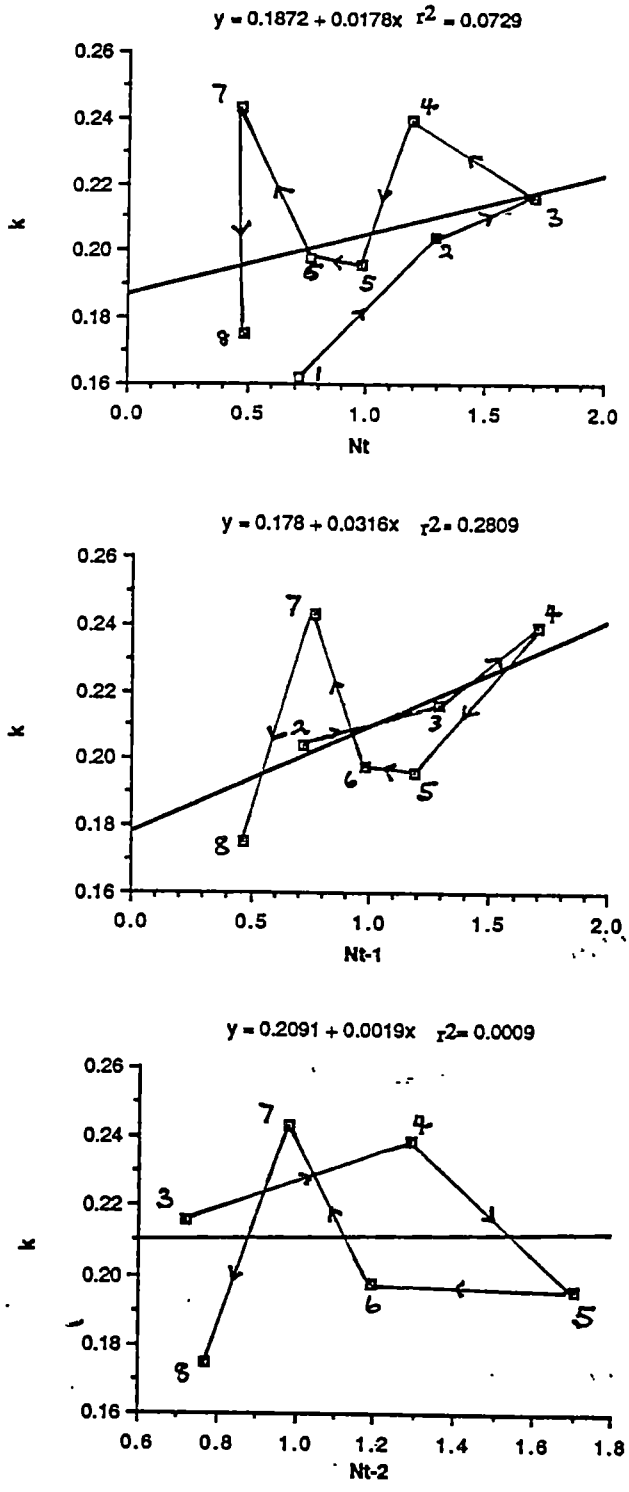


Fig.36.1

Plot of k value on N_t, N_{t-1} and N_{t-2}, where N_t is the combined number of 3rd, 4th and 5th instar nymphs in generation *t* at Kingston, 1986-89.

statistical grounds (Manly 1989). However in most instances the analysis indicated the general biological relationships. The plots of k against numbers of a particular stage at t, t-1, t-2, etc, as suggested by Berryman (1981) indicated that inverse density dependence of Varley and Gradwell analysis could be interpreted as a delayed density dependence through counter clockwise spirality and progressive increase in r^2 values in plots of k relative to populations in preceding generations until an abrupt change in r^2 indicated termination of the cycle.

3.4 Natural enemies

3.4.1 Predators

A number of insect predators were observed feeding on *C. thysanura* nymphs and adults on boronia plants at all study sites. Egg predation was not observed.

The major species observed to feed extensively on psyllids were coccinellids identified as *C. mellyi, Harmonia conformis* (Boisduval), *Coccinella repanda* Thunberg and *Coccinella undecimpunctata* Linnaeus. Other predators found feeding on psyllids were true spiders, small syrphid larvae (*Syrphus* sp.) and a trombidiid mite (family Trombidiidae).

Birds were occasionally seen on boronia plants in the afternoon and late evening, but their effect as predators of psyllids is more difficult to assess as a bird seen alighting on a boronia plant flew away on contact as the shoots provided no support.

3.4.1.1 Field observations

Occurrence of the various predators of boronia psyllids differ and their life cycles do not overlap with the life cycle of *C. thysanura* to the same extent at both Copping and Kingston (Figs 39, 40, 41 and 42). The result is that successive predators are present for most of the year with maximum abundance in spring, late summer and autumn.

Spiders are present on boronia throughout the year with peak numbers occurring

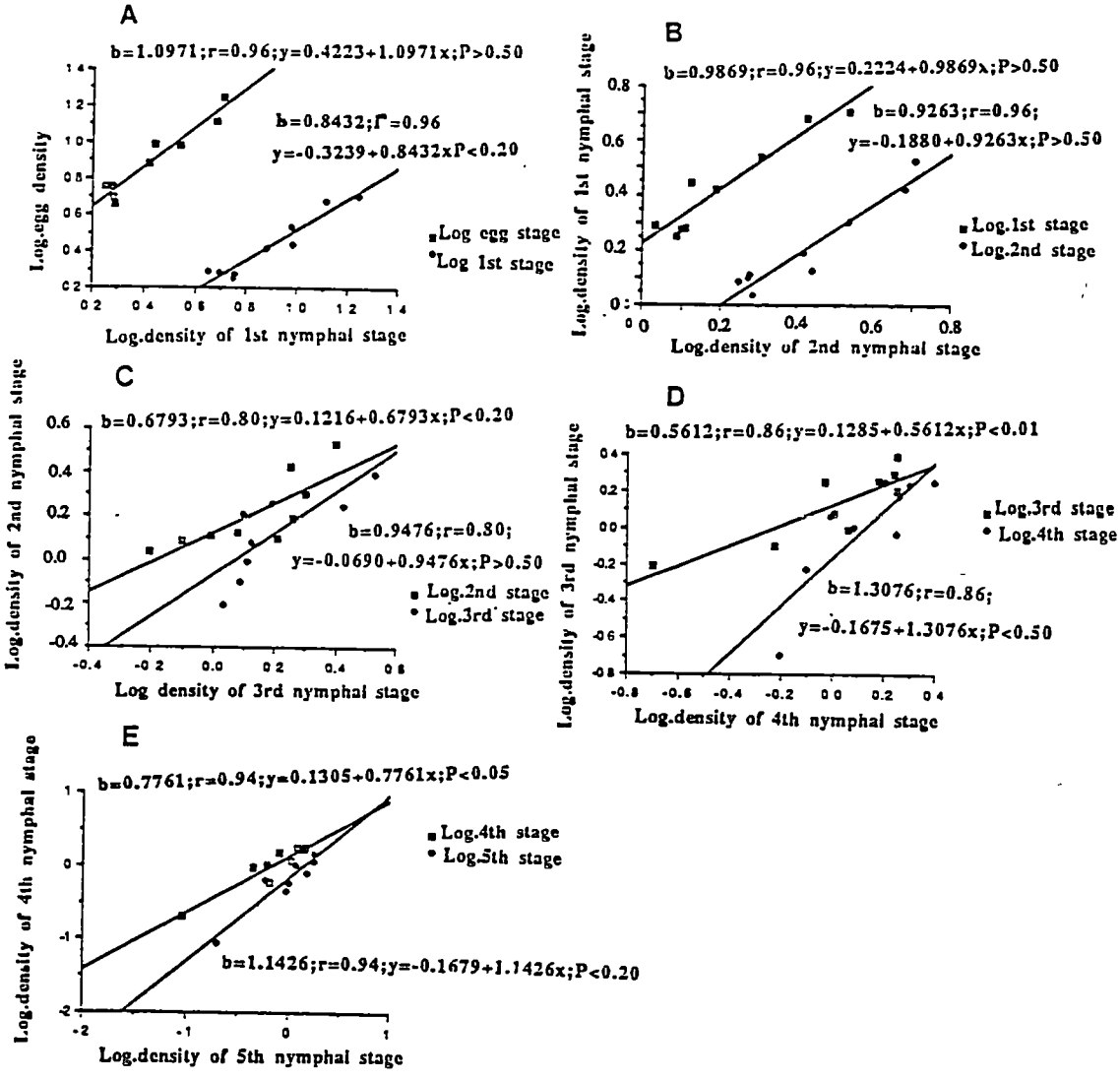


Fig. 37

Proof of a density relationship for *C.thysanura* egg and nymphal mortalities(Varley and Gradwell,1968) at Copping,1986-89.(Data from Table 26).

The slopes of the in "D and E" are significantly different from a slope of b=1, indicating that density dependence mortality is real in the 3rd,4th,and 5th nymphal stages.

The slopes of the curves in"A,B,and C" are not significantly different from a slope of b=1,indicating that density dependence mortality is not real in the egg,1st,and 2nd nymphal stages.

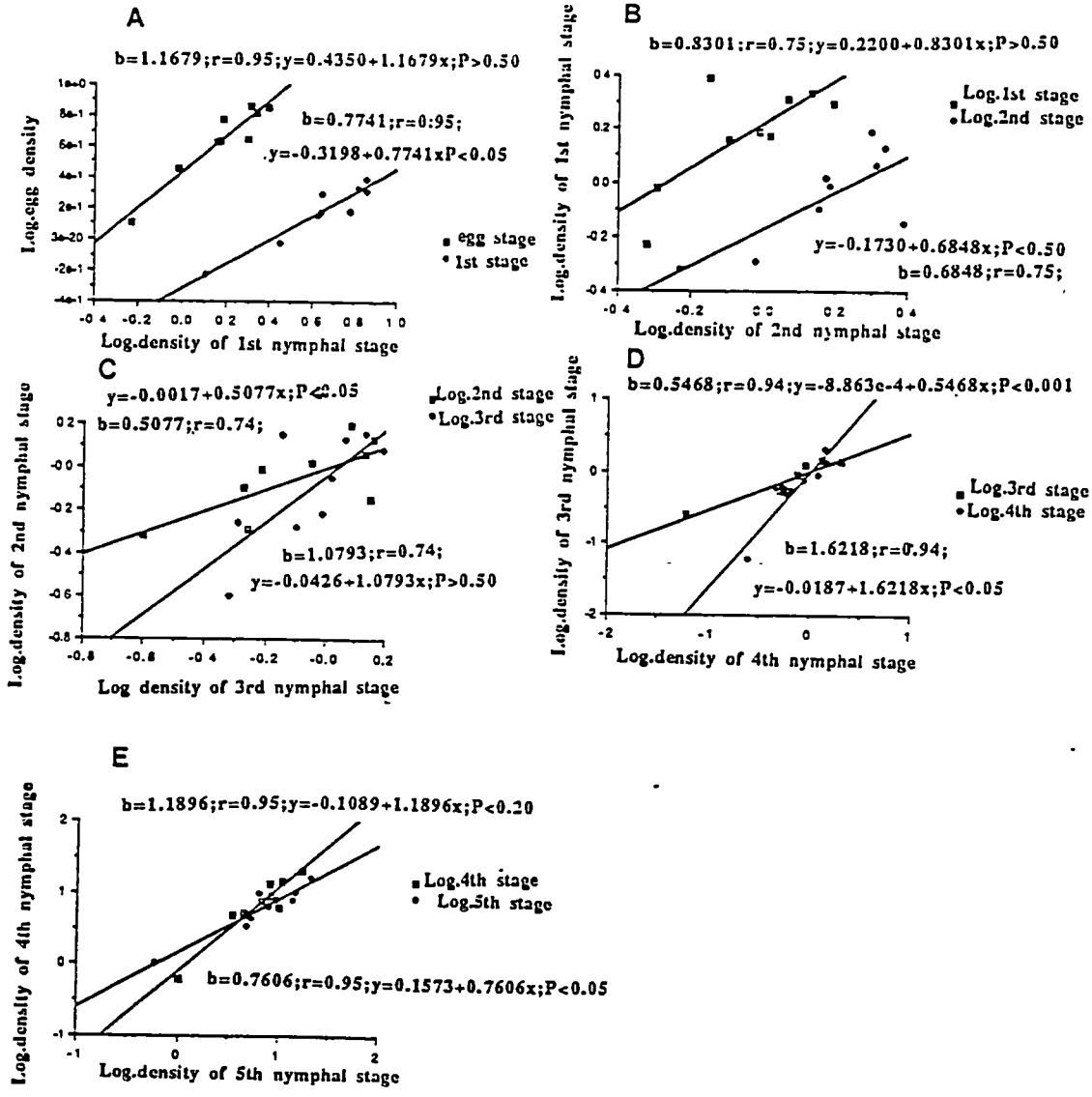


Fig. 38

Proof of a density dependent relationship for *C.thysanura* egg and nymphal mortalities at Kingston,1986-89.(Data from Table 27).

The slopes of the curves in "D and E" are significantly different from a slope of b=1,indicating that density dependence is real in the 3rd,4th,and 5th nymphal stages.

The slopes of the curves in "A,B,and C" are not significantly different from a slope of b=1,indicating that density dependence mortality is not real in the egg,1st,and 2nd nymphal stages.

in late summer and autumn (Figs 39A and 40A). The spiders were web-spinners and attacked by spinning a web around the terminal shoots of boronia plants and feeding indiscriminately on all insects trapped, including adult parasitoids.

The trombidiid mites were found preying on adult psyllids mainly in summer and autumn (Figs 20B and 21B). On many occasions they were found attached to the abdomen of *C. thysanura* adults, at all study areas.

Coccinellids were present in early spring and early summer (Figs 41A and 42A), being caught on sticky traps and usually on the side of the trap facing the eucalypt trees, indicating flight into the study area. The main coccinellid species found feeding on psyllids was *C. mellyi.*

Syrphid larvae were only found in spring (Figs 41B and 42B) feeding most commonly on third, fourth and fifth nymphal stages of *C. thysanura.* On one occasion, at Kingston, a syrphid larva was observed to attack an aphid, *A. gossypii,* on a terminal shoot infested with both psyllid nymphs and aphids, indicating that syrphid larvae are not specific predators of *C. thysanura.*

3.4.1.2 Laboratory feeding trials with *C. mellyi*

When four field collected mature adults of *C. mellyi* were maintained on *C. thysanura* fourth -fifth nymphal stages for four days, the mean number of nymphs consumed per adult per day was 32.56 (Table 35).

3.4.1.3 Availability of *C.thysanura* to its predators on field boronia.

Knowledge of the number of predators in relation to the the number of psyllids is important in determining predator effectiveness. The predator to psyllid numbers are outlined for each generation during 1987 to 1989 for all study areas (Tables 36,37 and 38).The results indicate that a high predator to psyllid number resulted in lower numbers of psyllids at all study areas an indication of predator effectiveness.

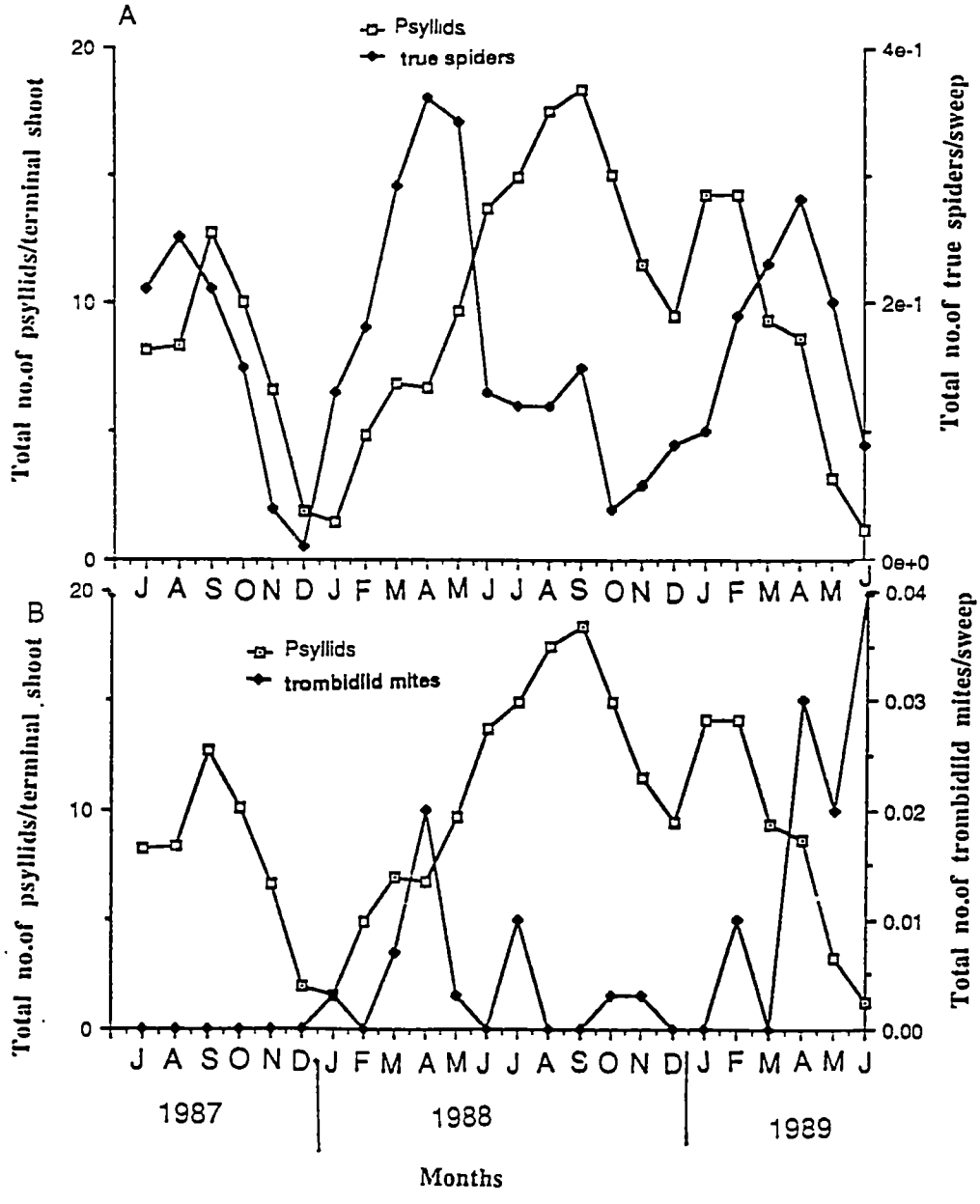


Fig.39

Comparison of the time of occurrence of(A) true spiders,and(B) trombidiid mites with *C.thysanura* adults and nymphs on boronia plants at Copping,1987-89.

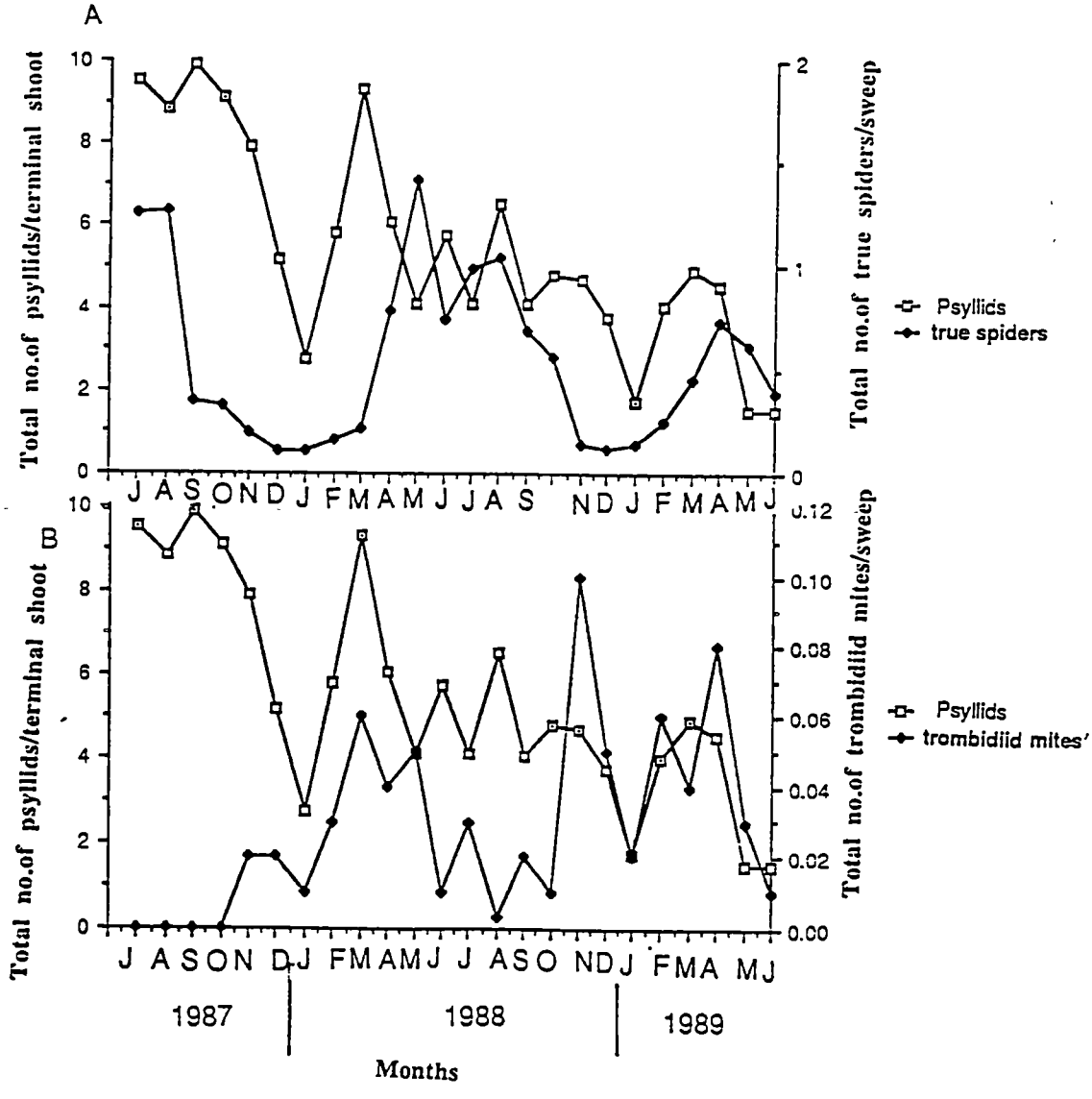


Fig. 40

Comparison of the time of occurrence of(A) true spiders,and(B) trombidiid mites with *C.thysanura* adults and nymphs at Kingston study area during the period 1987-89.

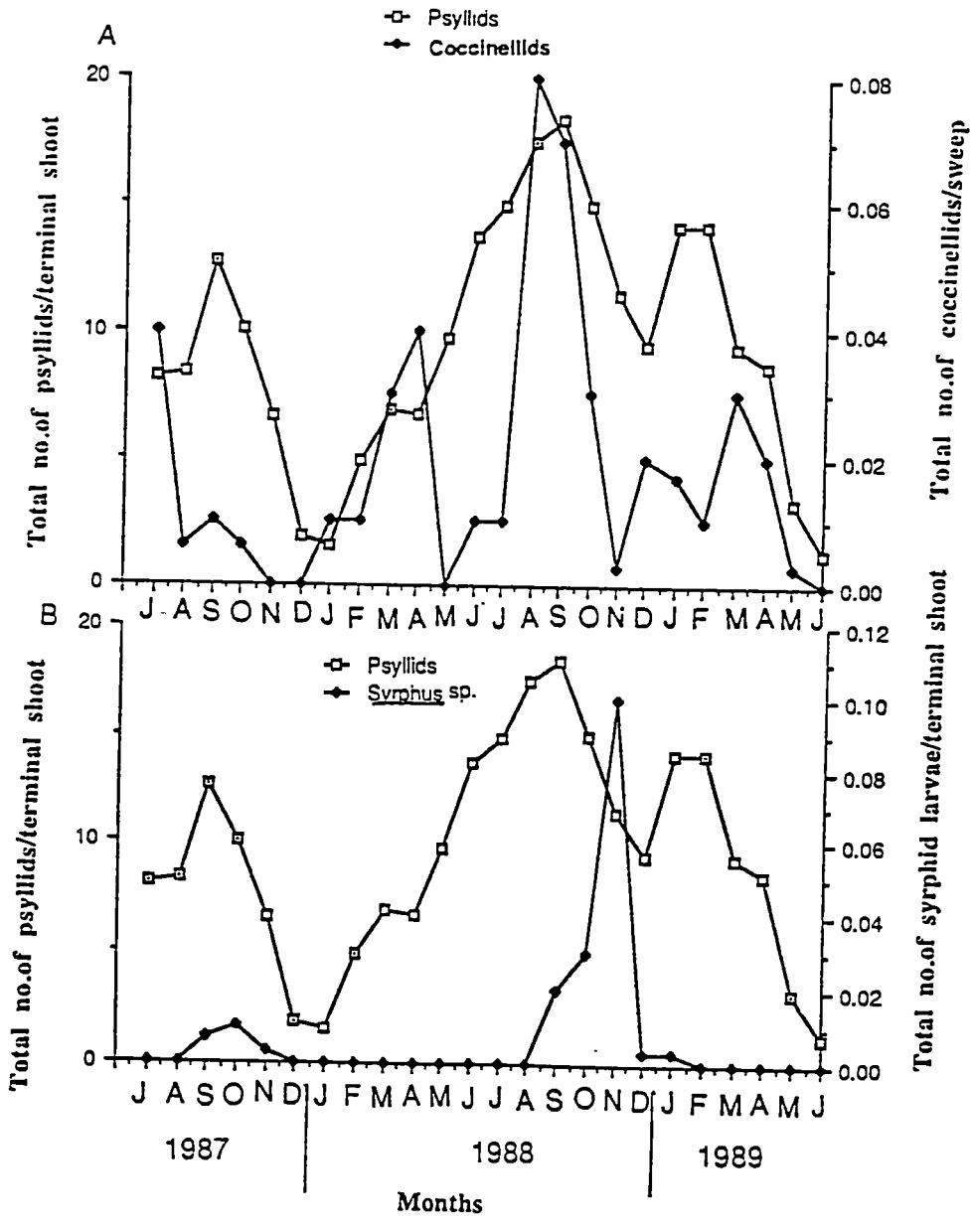


Fig. 41

Comparison of the time of occurrence of(A) coccinellids,and(B) *Syrphus* sp with *C.thysanura* adults and nymphs on boronia plants at Copping,1987-89.

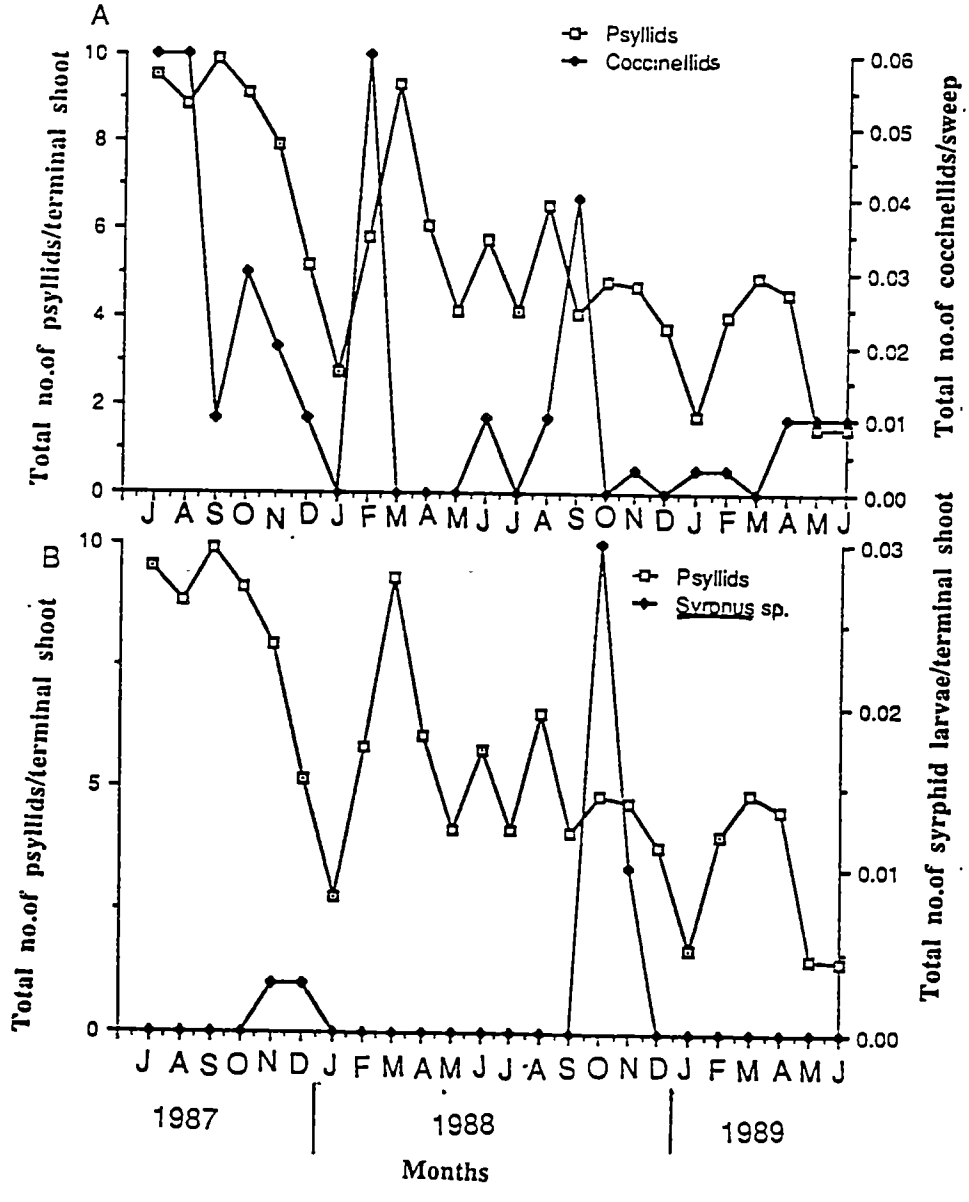


Fig.42

Comparison of the time of occurrence of (A) coccinellids,and(B) *Syrphus* sp. with *C.thysanura* adults and nymphs on boronia plants at Kingston,1987-89.

Table 35

The consumption of *C. thysanura* by a coccinellid predator *Cleobora mellyi* (Mulsant) under glasshouse conditions.(mean results of 4 replicates per treatment).

Treatment	Initial no.of nymphs per plant	Final no.of nymphs per plant after 4 days	Mean no.of nymphs consumed per day
1	160	26	33.50a
2	160	23	34.25a
3	160	27	33.25a
4	160	43	29.25a
Control	160	160	0
Total	800	279	130.25
Mean	40.0	13.95	32.56

Lsd(0.05)=8.05; Lsd(0.01)=11.29 Mean within rows followed by the same letter are not significantly different P>0.05.

The eggs of *C.thysanura* protected in the leaf axil were not considered as no egg predation was detected.

At Copping the data indicate that the predator to psyllid number was highest in summer 1988, and the autumn/winter generation in 1989, indicating that psyllids were more readily available to predators during these generations, but declined to a lower level in the winter and spring generations of 1988. This resulted in the higher psyllid numbers in these generations (Table 36). At Kingston predation was highest in the autumn/winter generations in 1989 (Table 37). At Summerleas, Howden, East Sassafras and Bakers Beach, predation was an important mortality factor in the 1989 season.

Table 36

The relation of predator numbers to *C. thysanura* numbers on boronia plants at Copping, 1986-89.

Year	Generation	Total no.of psyllids per 70 terminal shoots in samples.	Predator number / Psyllid number X 1000
1987	II(Autumn/winter)	5703	22
	III (Spring)	6559	21
1988	I (Summer)	3175	78
	II(Autumn/winter)	8591	22
	III (Spring)	14478	18
1989	I (Summer)	8475	27
	II(Autumn/winter)	1770	76

Table 37

The relation of predator numbers to *C. thysanura* numbers on boronia plants at Kingston, 1986-89.

Year	Generation	Total no.of psyllids per 70 terminal shoots in sample	Predator number / Psyllid number X 1000
1987	II(Autumn/winter)	6480	102
	III (Spring)	7120	61
1988	I (Summer)	3228	106
	II (Autumn/winter)	4866	94
	III (Spring)	3109	122
1989	I (Summer)	2791	156
	II(Autumn/winter)	581	546

Table 38

The relation of predator numbers to *C. thysanura* numbers on boronia plants at (A) Summerleas, (B) Howden, (C) East Sassafras and (D) Bakers Beach during the period 1988-89.

Year	Generation	Total no.of psyllids per 70 terminal shoots in samples	Predator number / Psyllid number X 1000
(A) Summerleas:			
1988	III (Spring)	2031	32
1989	I (Summer)	3655	21
	II (Autumn/winter)	564	115
(B) Howden:			
1988	III (Spring)	3129	45
1989	I (Summer)	1201	229
	II(Autumn/winter)	538	519
(C) East Sassafras:			
1988	III (Spring)	13753	7
1989	I (Summer)	3076	61
(D) Bakers Beach:			
1988	III (Spring)	4459	11
1989	I (Summer)	3522	48

3.4.2 Parasitoids

3.4.2.1 Egg parasitoids

No egg parasitoid was detected at any study site throughout the study period.

3.4.2.2 Nymphal parasitoids

The following parasitoids, all new species, were bred from *C. thysanura* nymphal stages during 1986/89 and identified to generic level only pending time for further identification: *Psyllaephagus* sp.1, *Psyllaephagus* sp.2 (Encyrtidae), *Moranila* sp. (Pteromalidae) and *Coccophagus* sp. (Aphelinidae). The important parasitoid was *Psyllaephagus* sp 1. A single female hyperparasitoid, *Epiblatticida* sp. was bred from

a psyllid nymph from Copping. All parasitoid species emerged from late nymphal stages (Tables 39 to 42).

Parasitoids attacked the first and second stage nymphs of *C. thysanura,* killing the host during the 4th and 5th nymphal stages, but occasionally at the 3rd. Parasitised *C. thysanura* nymphs became swollen during the third stage and prior to death changed colour ranging from black to orange-brown as did the dead mummies (Fig. 43). Adult parasitoids usually emerged from the host abdomen leaving a circular hole in the dead mummy. All parasitoids killed the host before emerging. Multiple parasitism was not recorded in *C. thysanura.*

In the analysis of effective parasitism in the life table, mortalities due to parasitoids were expressed as k_p values and were plotted against log density at Copping and Kingston (Fig. 44). The regression curve that resulted was negative and differed significantly from b=0 ($P<0.05$ for Copping and $P<0.01$ for Kingston). The temporal sequence of mortalities indicated the delayed nature of the density dependent action of the parasitoid complex with a lag of three generations to provide a negative feedback cycle (Fig.45.1).

The plot of k_{3-5} values against the ratio of parasitoids from t-1 relative to psyllid densities following predation in t was significant at both Copping and Kingston (Figs. 45.2 and 45.3). This indicated that if predation was severe then effective parasitism was increased resulting in a reduction in numbers of third to fifth stages. Predation and parasitism on the psyllid population acted as a delayed density dependent mortality factor, with a high density in one generation leading to high predator or parasitoid numbers in the next generation. The concerted action of the predators and parasitoids showed up in an anticlockwise spiral graph when k values for the successive generations are joined as indicated in (Figs. 35.1, 35.2, 36.1 and 45.1).

3.5 Some other factors affecting *C. thysanura* populations

3.5.1 Effect of Suction harvesting of flowers

The effects of high suction harvesting of boronia flowers on *C. thysanura* egg, nymph and adult populations are given in Tables 43, 44 and 45.

Fig.43

Parasitized C.thysanura 5th stage nymphs,swollen and not feeding.(x 5)

Table 39

Summary of parasitism of *C.thysanura* at Copping,1986-89.

Year	Generation	Total no.of late nymphal stages per terminal shoots in samples collected	Total no parasitized by *Psyllaephagus* sp.1	*Psyllaephagus* sp.2	*Moranila* sp.	*Cocophagus* sp.	Total
1986	III	1234	101	30	9	4	143
1987	I	1781	82	43	12	6	141
	II	2285	114	18	12	3	147
	III	1466	96	13	9	7	125
1988	I	779	107	10	1	0	118
	II	2435	116	16	22	2	156
	III	3154	173	33	46	4	256
1989	I	1068	92	38	28	2	160
	II	146	21	13	2	3	39

Table 40

Summary of parasitism of *C.thysanura* at Kingston,1986-89.

Year	Generation	Total no.of late nymphal stages per 70 terminal shoots in samples collected.	Total number parasitized by *Psyllaephagus* sp.1	*Psyllaephagus* sp.2	*Moranila* sp.	*Cocophagus* sp.	Total
1986	III	991	78	69	28	4	179
1987	I	1577	136	101	59	7	303
	II	2847	111	94	62	13	280
	III	2101	93	82	32	11	218
1988	I	685	68	49	31	3	151
	II	1381	86	62	32	5	185
	III	619	53	36	28	7	124
1989	I	646	67	49	26	2	144
	II	26	6	2	1	1	11

Table 41

Summary of parasitism of *C.thysanura* at (A) Summerleas and (B) Howden,1988-89.

Year	Generation	Total no.of late nymphal stages per 70 terminal shoots in samples collected.	Total number parasitized by *Psyllaephagus* sp.1	*Psyllaephagus* sp.2	*Moranila* sp.	*Cocophagus* sp.	Total
(A) Summerleas:							
1988	III	495	58	14	2	0	74
1989	I	732	81	20	1	0	102
	II	108	12	7	1	1	22
(B) Howden:							
1988	III	323	23	11	5	0	39
1989	I	263	32	10	1	0	43
	II	68	10	5	2	0	17

Table 42

Summary of parasitism of *C.thysanura* at (A) East Sassafras and (B) Bakers Beach,1988-89.

Year	Generation	Total no.of late nymphal stages per 70 terminal shoots in samples collected.	Total number parasitized by *Psyllaephagus* sp.1	*Psyllaephagus* sp.2	*Moranila* sp.	*Cocophagus* sp.	Total
(A) East Sassafras:							
1988	III	3737	138	124	71	0	333
1989	I	473	46	32	9	0	87
(B) Bakers Beach:							
1988	III	1094	79	46	0	0	125
1989	I	491	41	31	1	0	73

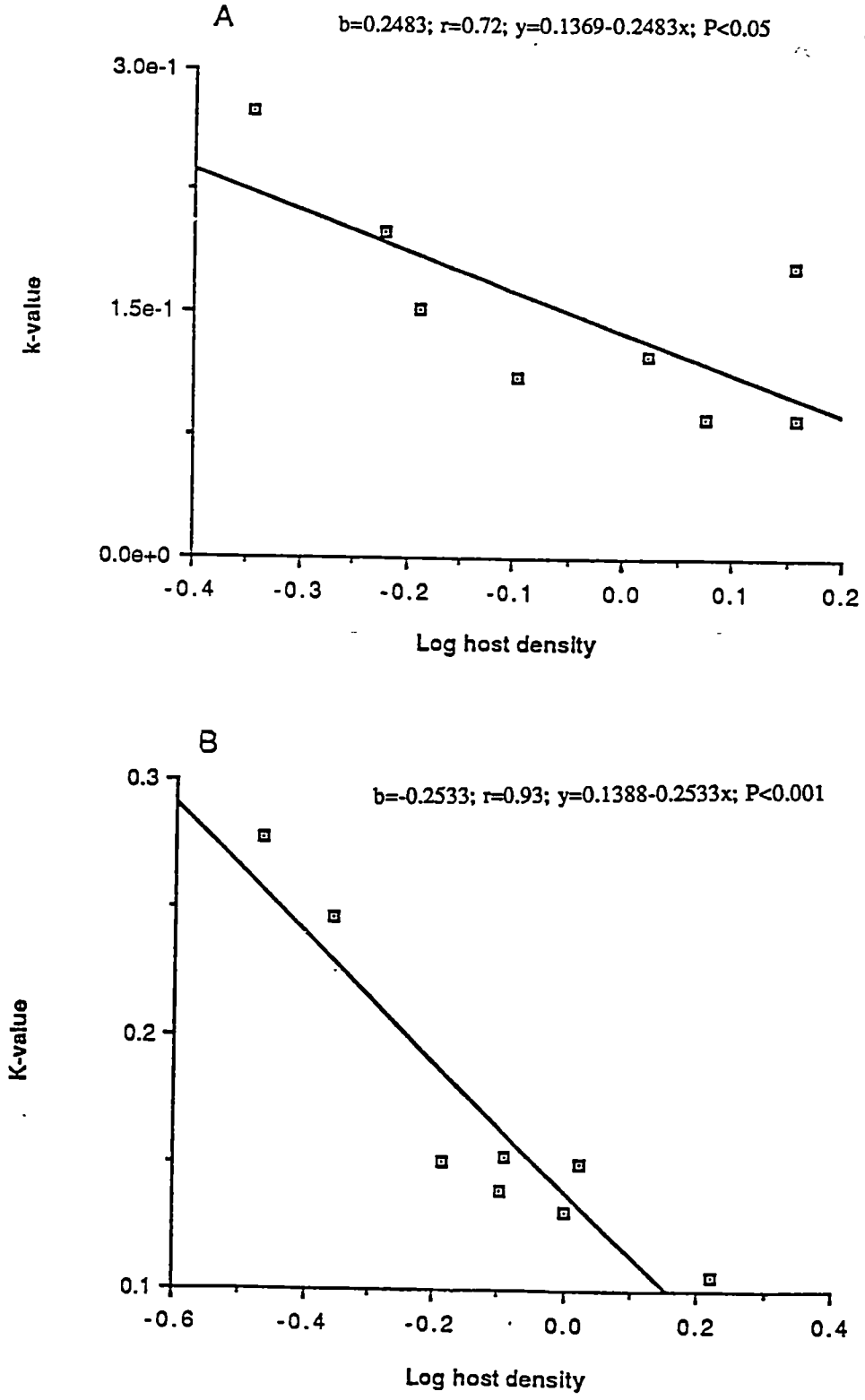


Fig.44

Parasitism of the chief parasitoids of *C.thysanura* expressed as k-values plotted against the host densities on which they acted in the study areas at (A) Copping,and (B) Kingston,1986-89.

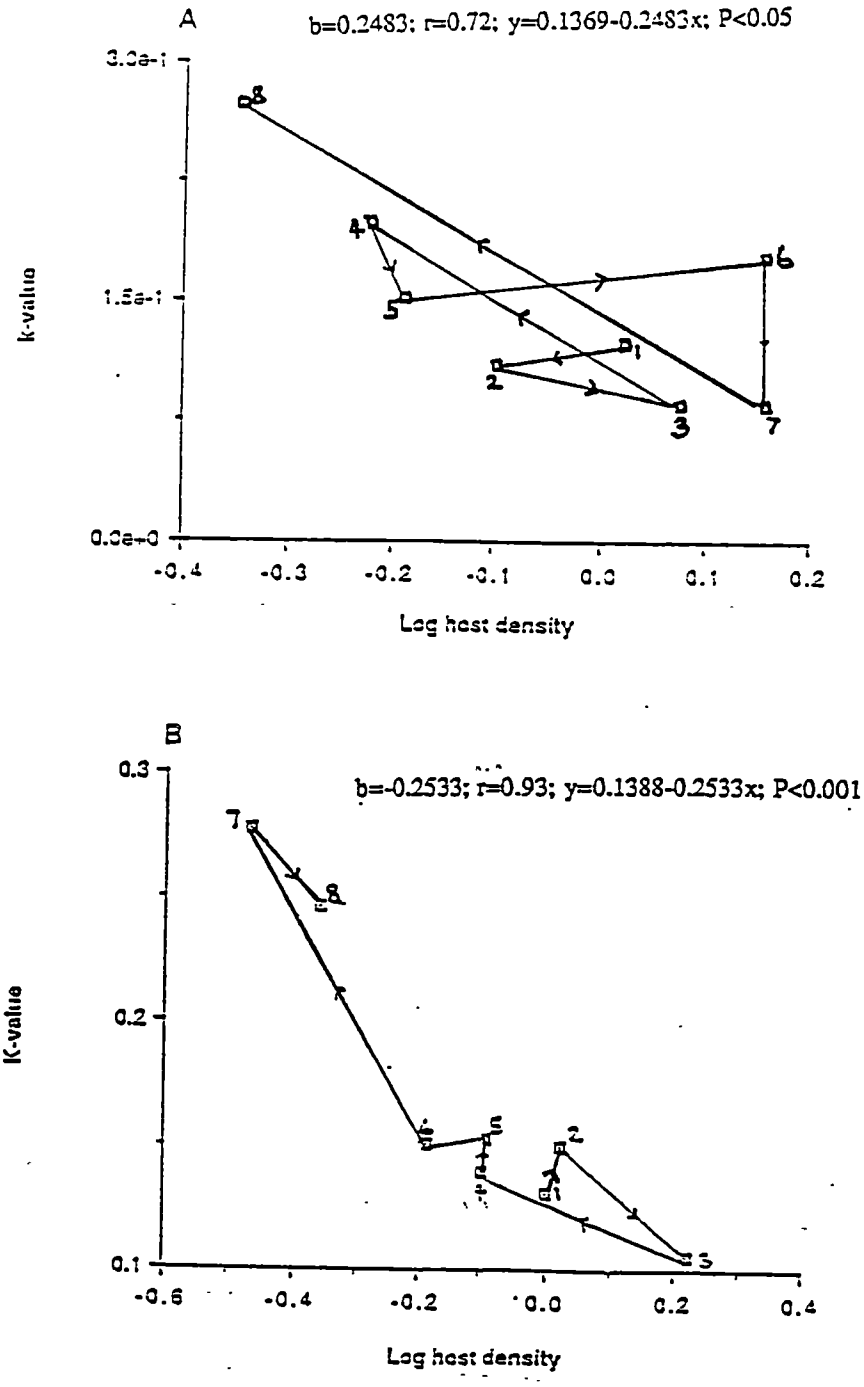


Fig. 45

The k-values for parasitism of *C.thysanura* plotted against the host densities on which they acted with points joined in time series at (A) Copping and (B) Kingston, 1986-89.

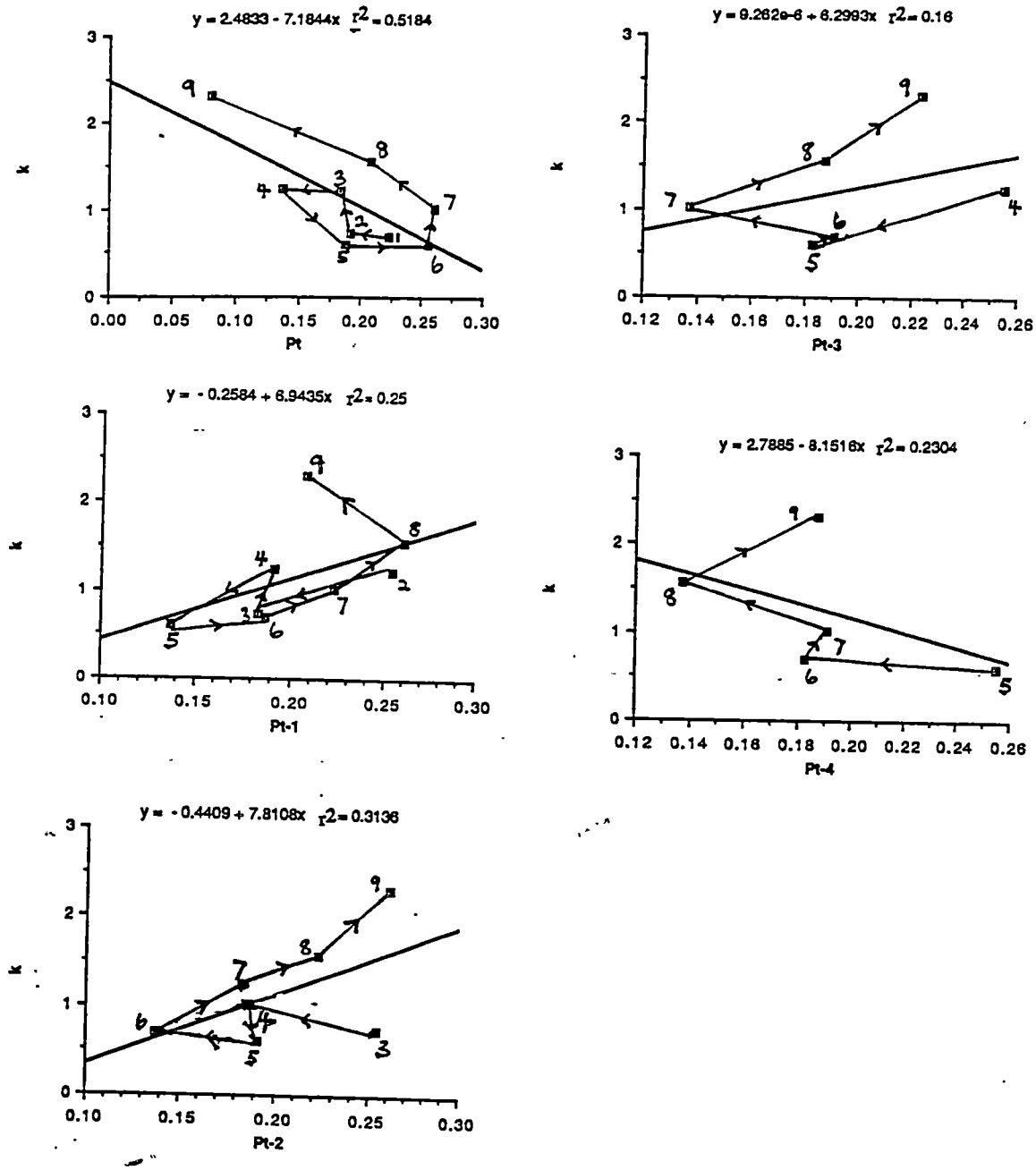
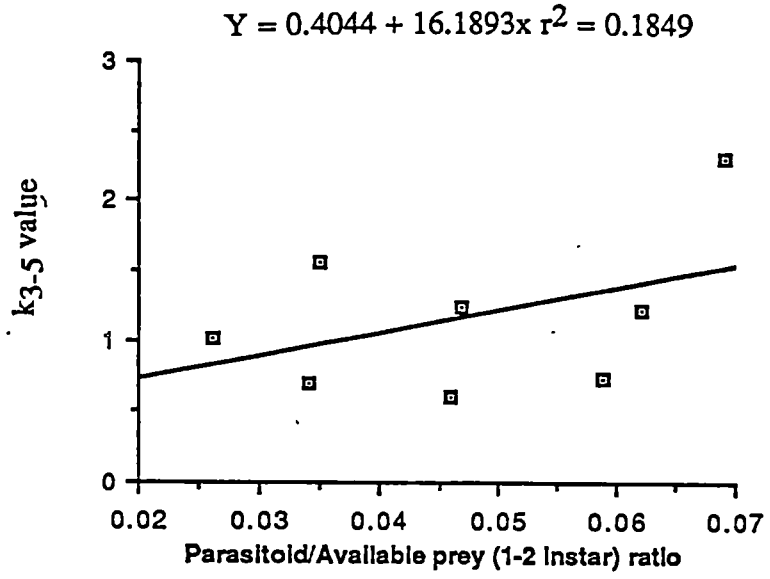


Fig.45.1

Plot of k value on P_t, P_{t-1}, P_{t-2}, P_{t-3} and P_{t-4}, where P_t is the number of *C.thysanura* nymphs parasitized in generation *t* at Copping, 1986-89.



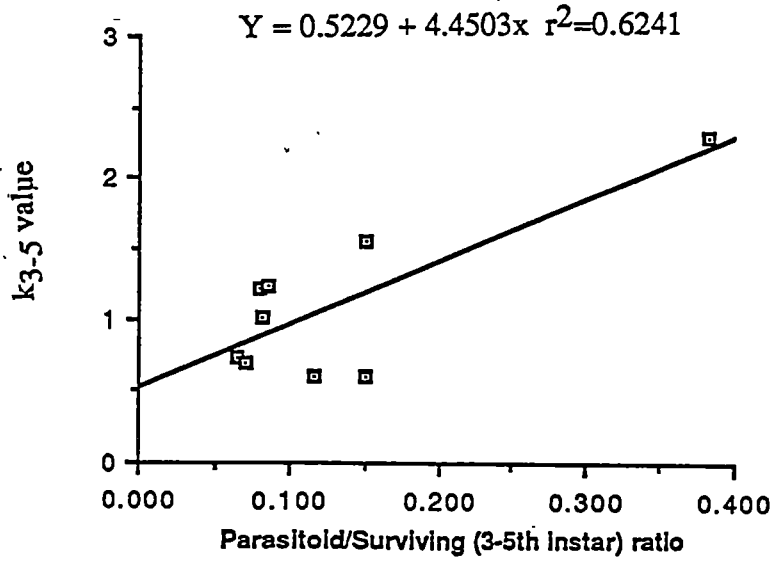
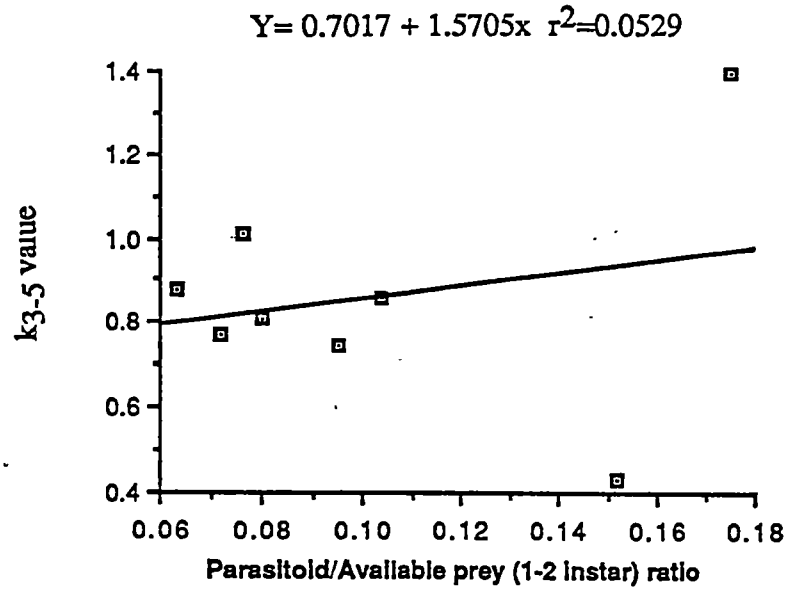


Fig. 45.2

Plot of combined k_{3-5} value on parasitoid available prey (1st and 2nd instar) and parasitoid to surviving 3rd to 5th instar ratios at Copping, 1986-89.



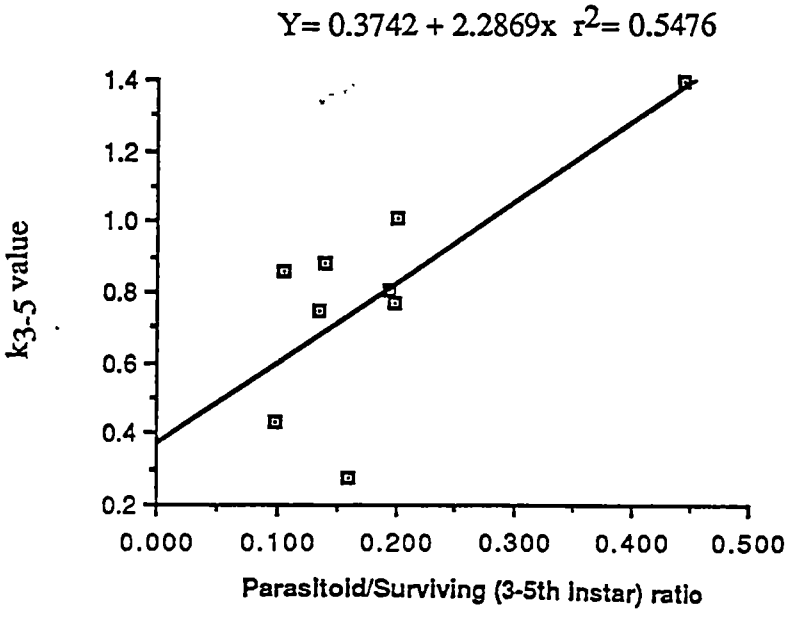


Fig. 45.3

Plot of combined k_{3-5} value on parasitoid available prey (1st and 2nd instar) and parasitoid to surviving 3rd to 5th instar ratios at Kingston, 1986-89.

Suction harvesting of flowers (Fig 46) caused mortalities of 69.4 per cent, 73.0 per cent and 87.2 per cent for *C.thysanura* eggs (Table 43), nymphs (Table 44) and adults (Table 45), respectively.

Table 43

Effect of suction harvesting of boronia flowers on *C.thysanura* eggs at Copping during 1987-88 season. (Mean results of 70 terminal shoots per treat ment).

Treatment	Total no.of eggs per 70 terminal shoots in samples 24 hrs.before harvesting of flowers	Total no.of eggs per 70 terminal shoots in samples 24 hrs after harvesting of flowers	Mortality (Per cent)
1. Harvested plots	2952	902	69.4
2. Unharvested plots	1334	1462	-9.60
Total	4286	2364	

Table 44

Effect of suction harvesting of boronia flowers on *C.thysanura* nymphs at Copping during the 1987-88 season.(Mean results of 70 terminal shoots per treatment).

Treatment	Total no.of nymphs per 70 terminal shoots in samples 24 hrs before harvesting of flowers.	Total no.of nymphs per 70 terminal shoots in samples 24 hrs after harvesting of flowers.	Mortality (Per cent)
1. Harvested plots	1633	441	73.0
2. Unharvested plots	925	992	-7.24
Total	2558	1433	

Fig.46
Suction harvesting of boronia flowers.

Table 45

Effect of suction harvesting of boronia flowers on *C.thysanura* adults. (mean results of 100 sweeps per treatment).

Treatment	Total no.of psyllid adults per sweep 24 hrs.before harvesting of flowers.	Total no.of psyllid adults per sweep 24 hrs.after harvesting of flowers.	Mortality (Per cent)
1. Harvested plots	19.00	2.44	87.2
2. Unharvested plots	18.24	18.27	-0.2
Total	37.24	20.71	

3.5.2 Effect of pruning of terminal shoots on *C. thysanura*

The effect of pruning off the top 15 cm of the terminal shoot on *C. thysanura* egg and nymphal populations is shown on Fig 47. Seven days after pruning *C. thysanura* egg and nymphal populations were reduced by 66.7 percent (eggs) and 51.6 per cent (nymphs) to the pre harvest counts. Counts at 28 days post harvest showed rapid recovery of the psyllid eggs. This was related to the growth of new boronia shoots which were attractive to *C.thysanura* adult females for oviposition.(Fig 47A).

3.5.3 Effect of fertiliser applications

The effects of fertiliser (NPK) applications on *C. thysanura* adults, nymphs and eggs, and the growth of boronia plants, are shown in Figs 48 and 49. Fertilised plants supported a higher ($P<0.01$) population of *C. thysanura* adults, particularly females, than did unfertilised plants (Fig 48) and, consequently, higher numbers of eggs and nymphs ($P<0.01$) (Fig 49 AB). Fertilised plants, despite their supporting high numbers of psyllids, recorded more growth than ($P<0.05$) did unfertilised plants (Fig 49C).

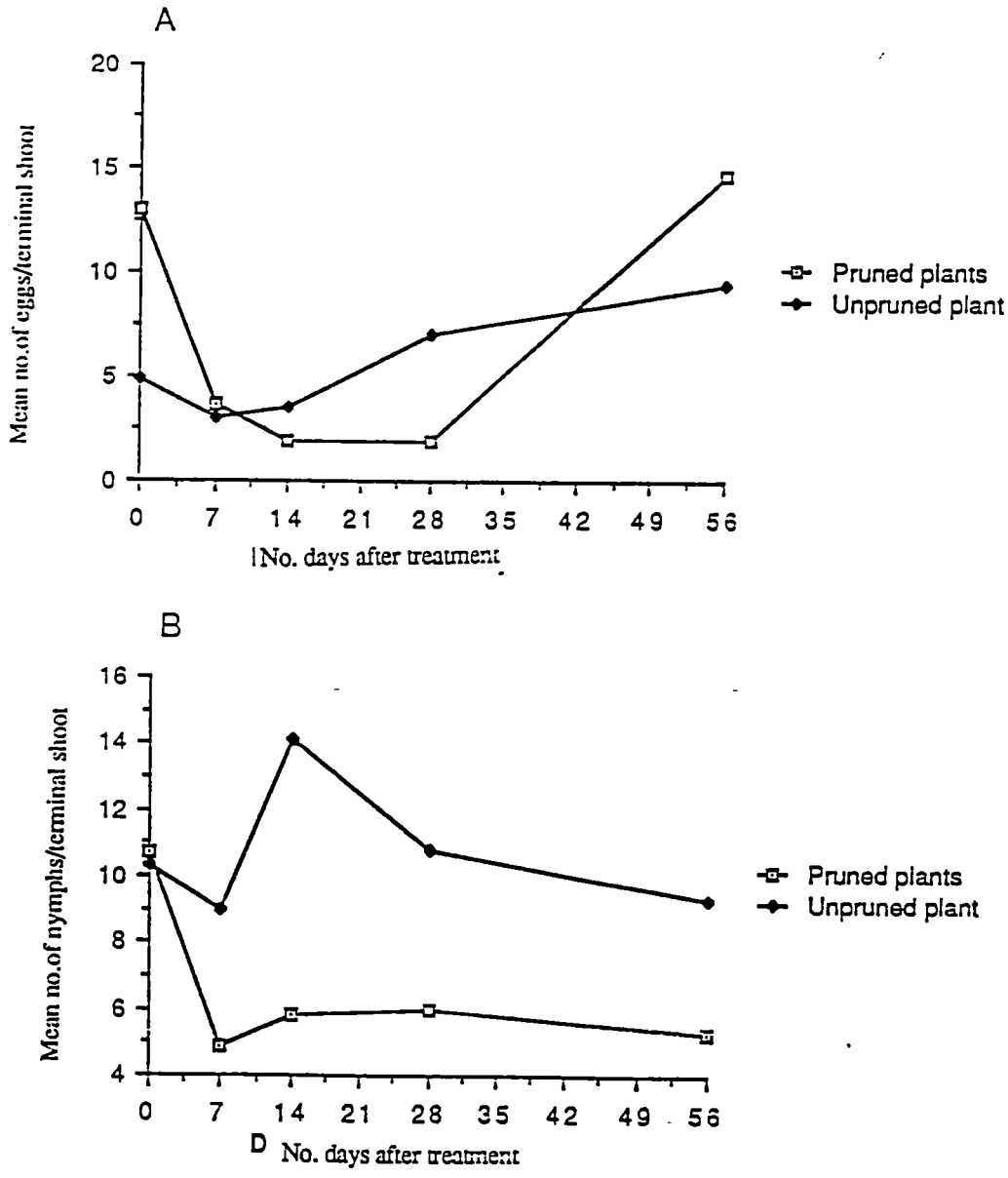


Fig. 47

The effect of pruning of the terminal shoots of boronia plants on the (A) eggs,and (B) nymphal stages of *C.thysanura.*

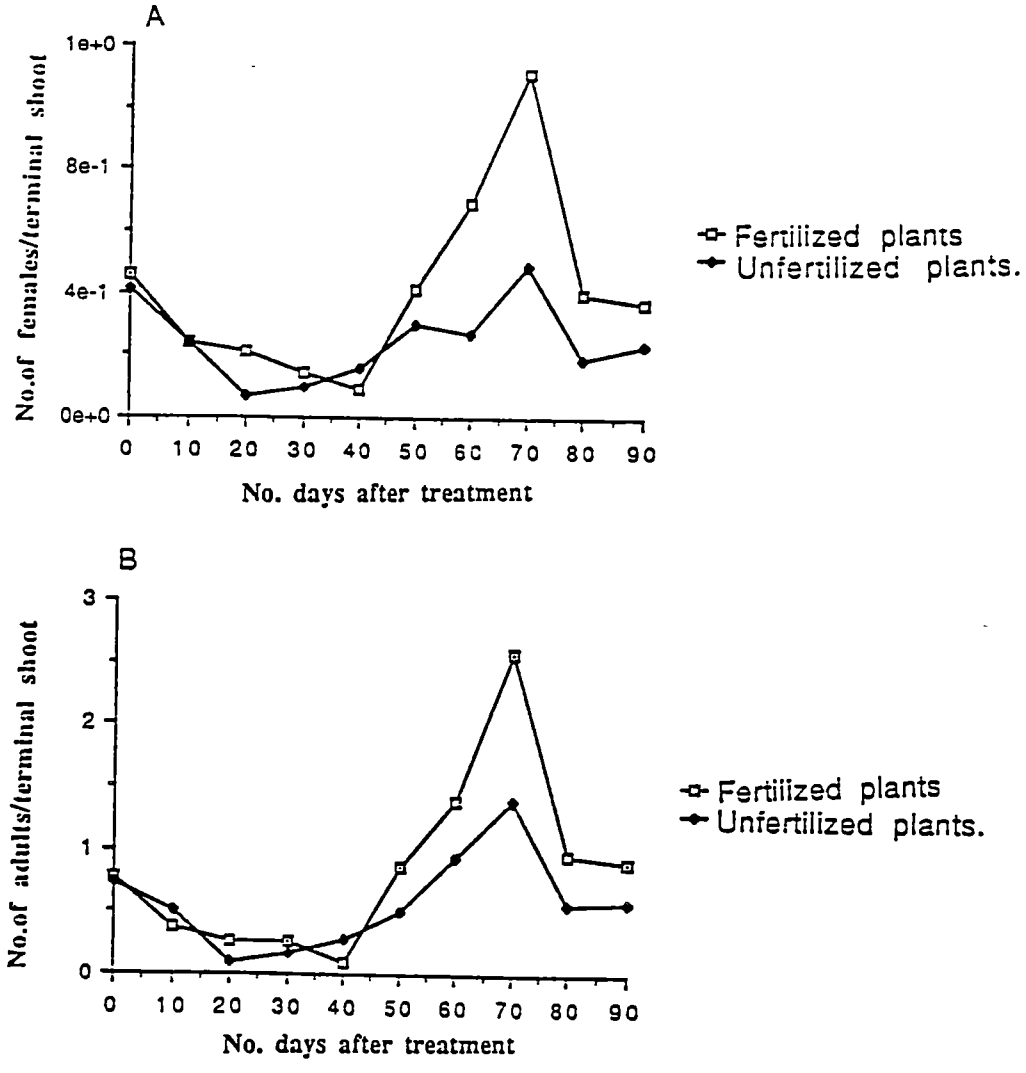


Fig. 48

The effect of fertilizer application on the number of *C.thysanura* per terminal shoot of (A) female, and (B) male and female adults on boronia plants.

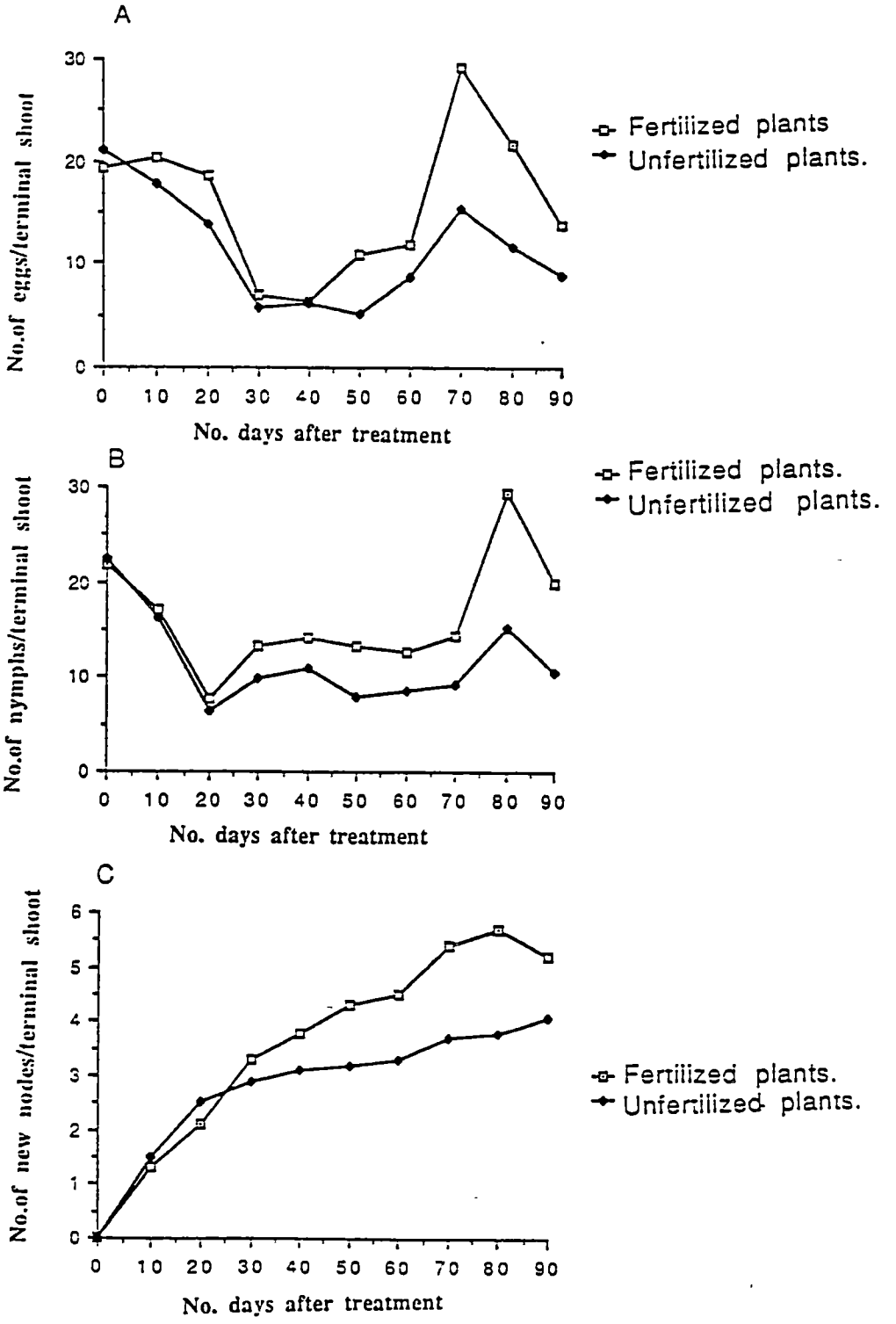


Fig. 49

The effect of fertilizer application on the number per terminal shoot of (A) eggs,and (B) nymphs of *C.thysanura*,and (C) new nodes formed on boronia plants.

3.5.4 Crowding effect on *C. thysanura* populations

3.5.4.1 Effect of crowding on the duration of the developmental period of the psyllid

The duration of the psyllid developmental period correlated positively ($P<0.02$) with population density being extended with population increase (Fig 50A).

3.5.4.2 Effect of crowding on the mortality of *C. thysanura* nymphs

Nymphal mortality increased as psyllid population density increased at all nymphal stages of the psyllid ($P<0.005$) (Fig 50B).

3.5.4.3 Effect of crowding on the weight and fecundity of emerging *C. thysanura* adults

The effect of crowding on the weight and fecundity of emerging *C. thysanura* adults is given in Fig 51.

Smaller and therefore lighter *C. thysanura* adults were produced at higher population densities and weight differences at low and high densities differed significantly ($P<0.01$) for both males and females (Fig 51A). The weight of emerging adults increased from a nymphal population density of 10 nymphs per shoot peaking at 30 nymphs per shoot then falling to a minimum weight of 0.06mg (males) and 0.085mg (females) at densities of 60 nymphs per shoot.

The fecundity of the psyllid female was also reduced after the population density of 30 nymphs per shoot was exceeded. *C. thysanura* females bred to maturity at population densities of 10 psyllids per shoot produced significantly more eggs ($P<0.01$) than those bred to maturity at densities greater than 30 nymphs per shoot (Fig 51B).

3.5.4.4 Effect of crowding on the fecundity of *C. thysanura* females

The total number of eggs laid per plant increased as crowding of adult females increased ($P<0.001$), although the number of eggs laid per individual female declined ($P<0.001$) (Fig 52).

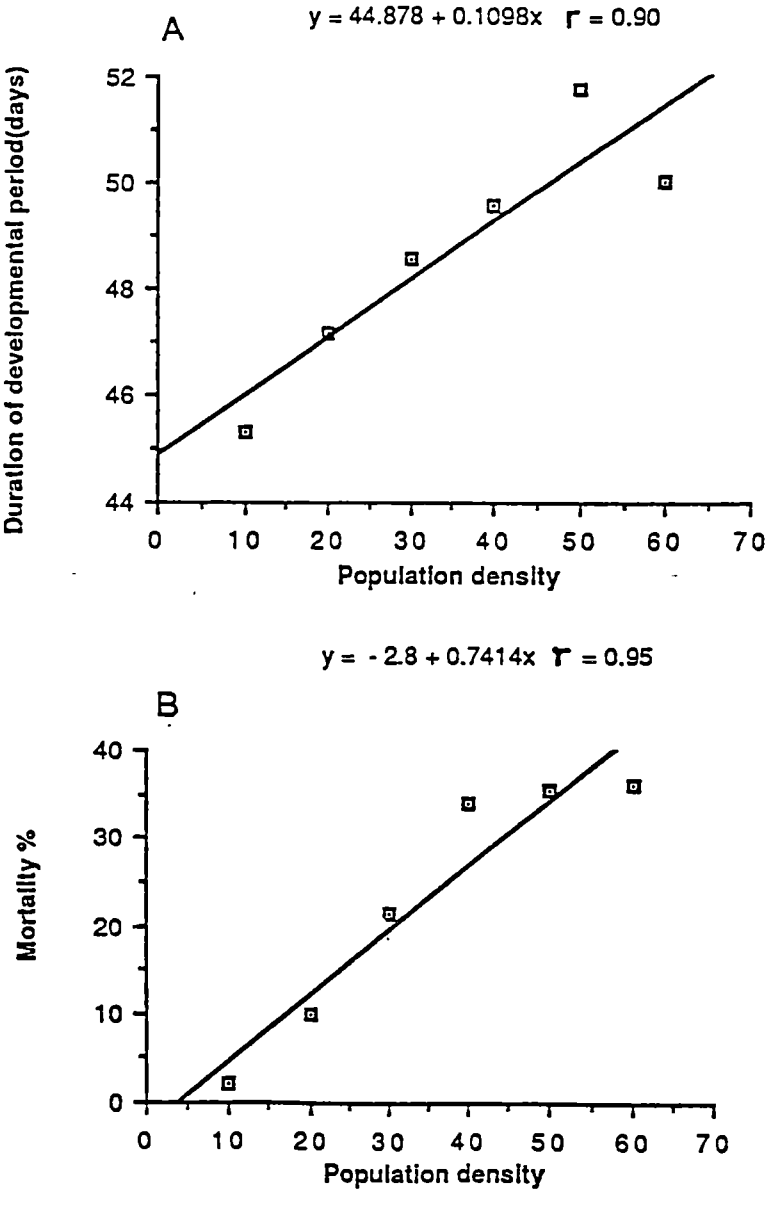


Fig. 50

The effect of crowding on the (A) duration of the developmental stages, and (B) mortality of *C.thysanura* nymphs. Data from glasshouse experiment.

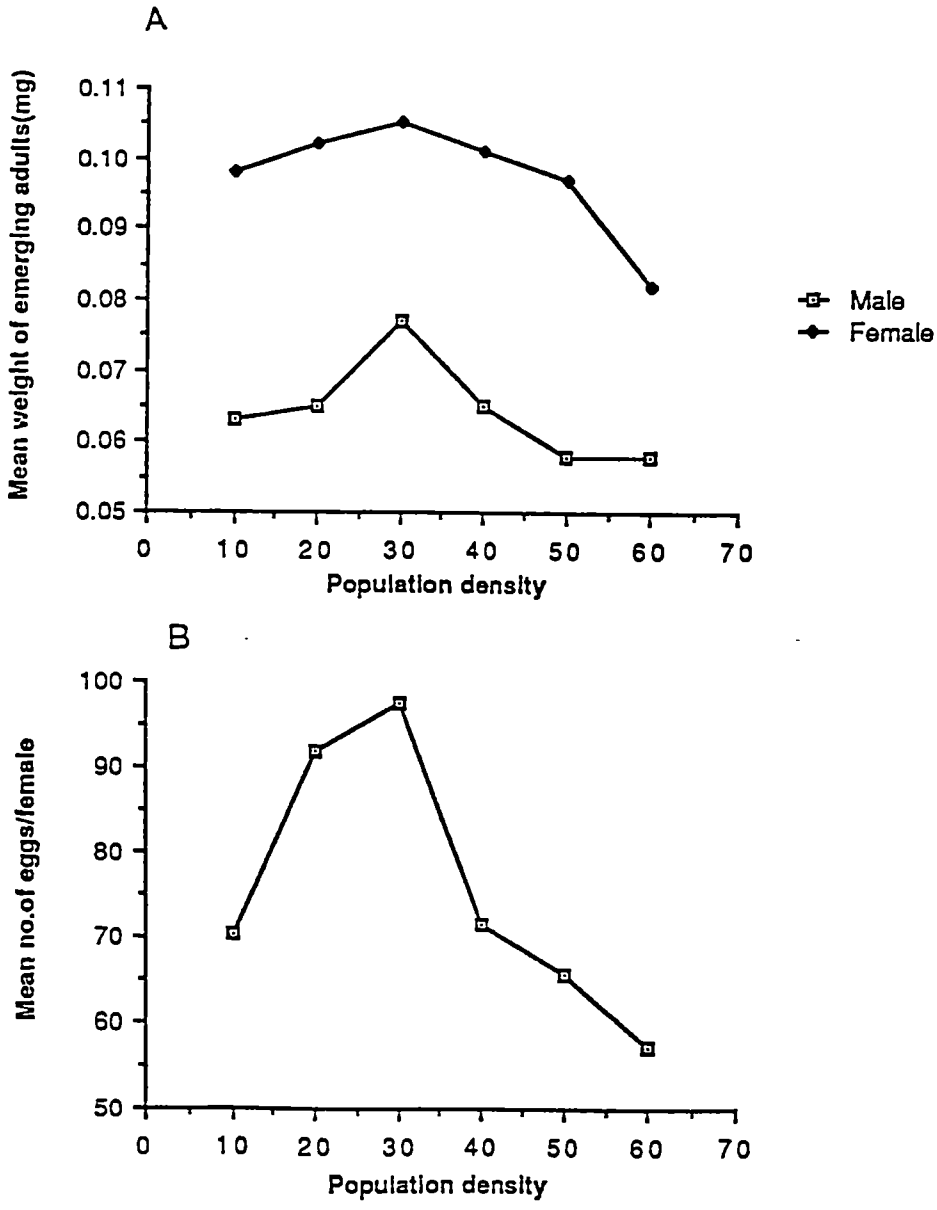


Fig. 51

The effect of crowding during immature (nymphal) stages of *C.thysanura* on the (A) weight(mg) of emerging adults,and (B) number of eggs laid per emerged female. Data from glasshouse experiment.

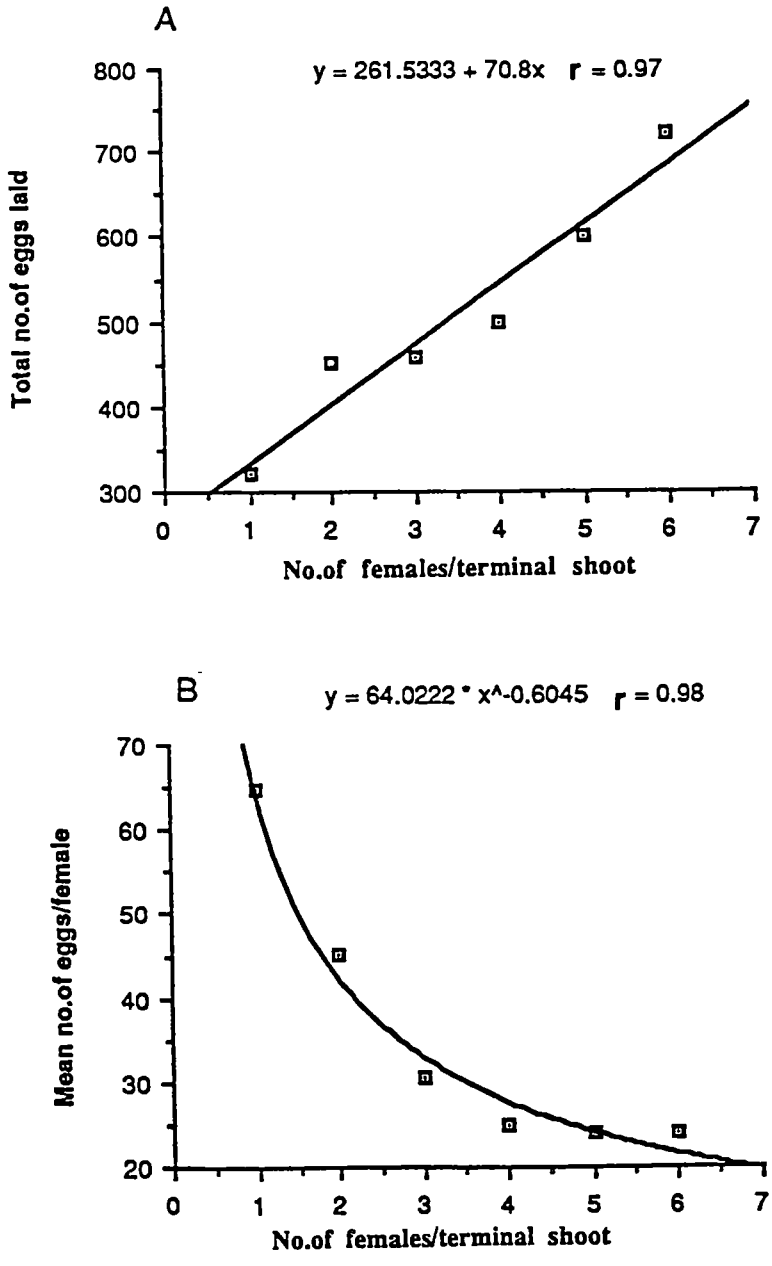


Fig. 52

The effect of crowding *C.thysanura* adult females on (A) total fecundity and (B) the number of eggs laid per female. Data from glasshouse experiment.

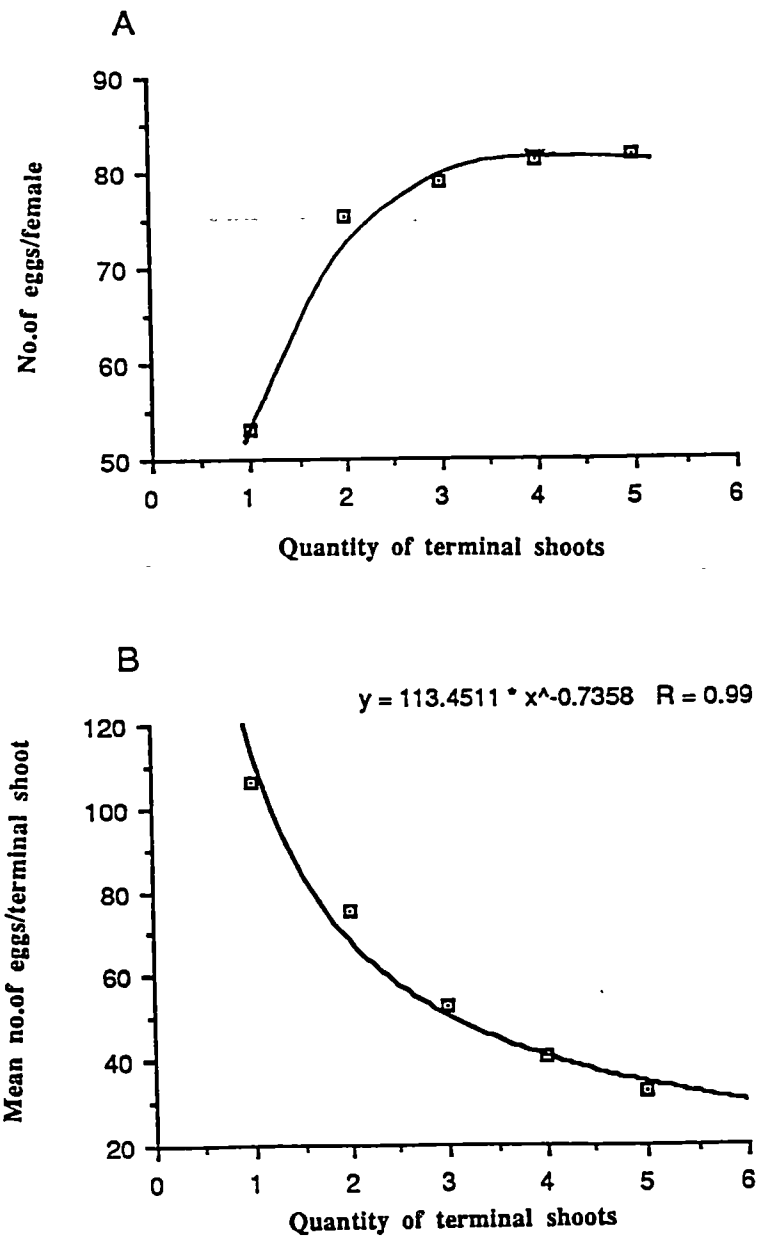


Fig. 53

The effect of quantity of terminal shoots or shoots suitable for oviposition on (A) the number of eggs laid per female,and (B) the number of eggs laid per terminal shoot by *C.thysanura* females.

3.5.4.5 Availability of terminal shoots and *C.thysanura* fecundity.

As the quantity of suitable terminal shoots increased, the number of eggs laid per female increased to a maximum rate of 82.5 eggs per female after which further addition of shoots had no effect on the number of eggs laid (Fig 53A). As the quantity of terminal shoots for oviposition increased, the number of eggs laid per female per terminal shoot decreased ($P<0.001$). The results indicate that *C.thysanura* adult females with access to numerous suitable shoots dispose their eggs thus lessening intraspecific competition (Fig 53B).

3.5.5 The interaction between *A. gossypii* and *C. thysanura* on boronia plants

3.5.5.1 Relationship of *C. thysanura* and *A. gossypii* under field conditions

The numbers of *A. gossypii* and *C. thysanura* compared with the number of *C. thysanura* eggs per terminal shoot are shown in Tables 46, 47 and 48 for all study areas.

As the numbers of *A.gossypii* on the boronia plants increased the numbers of *C.thysanura* adults and eggs also decreased. The highest number of aphids per shoot were recorded in the autumn/winter (second) generation in 1989 at all study areas and these resulted to lower numbers of *C.thysanura* adults and eggs per terminal shoot.

3.5.5.2 Laboratory trials

3.5.5.2.1 Effect of *A. gossypii* on *C. thysanura* oviposition.

The total number of eggs per plant was significantly higher ($P<0.01$) on plants which were infested with only *C. thysanura* adults (133) than plants infested with both *C. thysanura* and *A. gossypii* (22.20), indicating that the presence of the aphid suppressed psyllid oviposition (Table 49).

Table 46

The effect of *A.gossypii* presence on numbers of *C.thysanura* adults and eggs per terminal shoot.(Copping 1986-89).(All estimates multiplied by 1000 to avoid decimals).

Year	Generation	No.of psyllid eggs per terminal shoot X 1000	No.of psyllid adults per terminal shoot X 1000	Number of aphids per terminal shoot X 1000
1987	III (Spring)	9560	70	129
1988	I (Summer)	5610	200	95
	II (Autumn/winter)	9460	400	0
	III (Spring)	17520	240	41
1989	I (Summer)	12910	50	310
	II(Autumn/winter)	4500	30	600

Table 47

The effect of *A.gossypii* presence on numbers of *C.thysanura* adults and eggs per terminal shoot. (Kingston, 1987-89).

Year	Generation	No.of psyllid eggs per terminal shoot X 1000	No.of psyllid adults per terminal shoot X 1000	No.of aphids per terminal shoot X 1000
1987	II(Autumn/winter)	7130	520	8
	III (Spring)	6580	200	145
1988	I (Summer)	4440	220	209
	II(Autumn/winter)	4350	160	288
	III (Spring)	6000	60	667
1989	I (Summer)	4250	90	952
	II (Autumn/winter)	1280	10	3411

Table 48

The effect of *A.gossypii* presence on the numbers of *C.thysanura* adults and eggs per terminal shoot at (A) Summerleas and (B) Howden, 1988-89.

Year Generation	No.of psyllid eggs per terminal shoot X 1000	No.of psyllid adults per terminal shoot X 1000	No.of aphids per terminal shoot X 1000
(A) Summerleas:			
1988 III (Spring)	7660	70	500
1989 I (Summer)	12110	68	956
II (Autumn/Winter)	3920	15	12133
(B) Howden:			
1988 III (Spring)	16610	14	7567
1989 I (Summer)	2940	30	19285
II(Autumn/Winter)	1860	10	42500

3.5.5.2.2 The interaction of *C. thysanura* and *A. gossypii* on the growth of boronia

The presence of *A. gossypii* on boronia plants deterred *C. thysanura* from establishment and oviposition (Fig. 54). This is indicated by the higher number of new nodes formed per terminal shoot on plants infested with both psyllids and aphids compared with those infested only with psyllids. The growth of the plants infested with both psyllids and aphids did not differ significantly ($P>0.05$) from either that of uninfested plants or those infested with only *A. gossypii* (Fig. 54). The data indicate that *A. gossypii* alone can cause significant damage ($P<0.05$) to the growth of boronia plants, but compared with the damage caused by *C. thysanura,* the damage was significantly lower ($P<0.01$) (Fig. 33).

It was observed throughout the study that psyllids on psyllid-aphid infested plants spent long periods on boronia leaflets away from the leaf axils which were occupied by aphids. Psyllids remained motionless on the leaflets and, on some occasions, preferred to move to less suitable leaflets at the base of the plant. Many psyllids refused to settle on plants moving to the sides of the plastic cages.

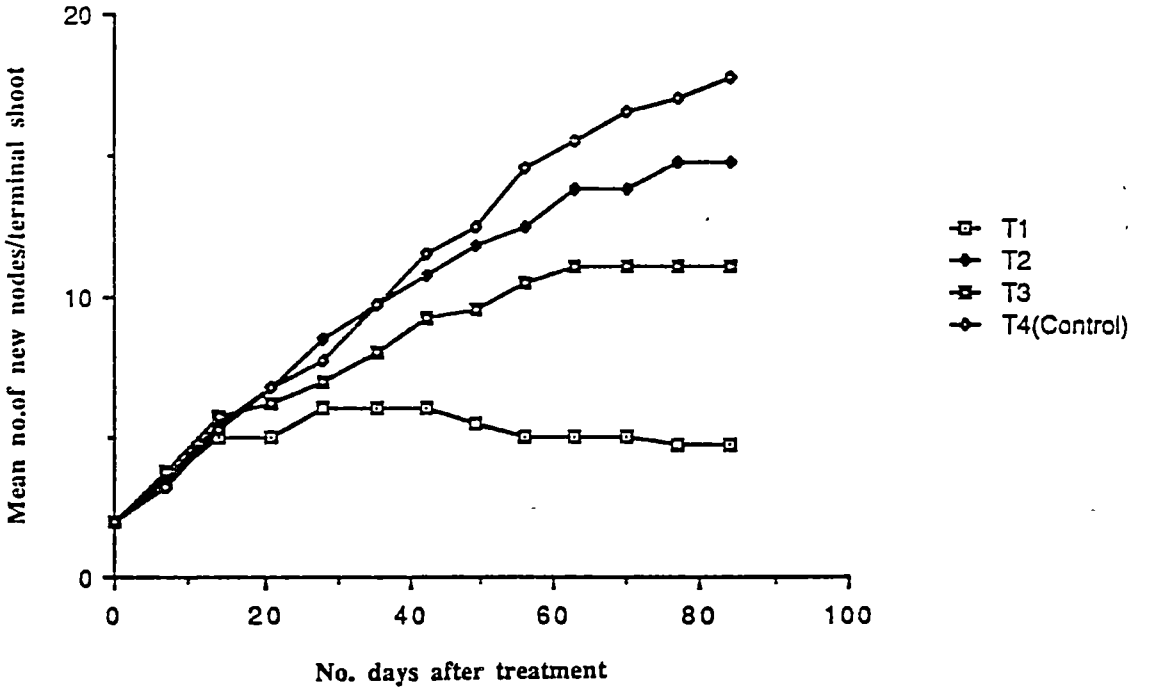


Fig. 54

The interaction of *A.gossypii* and *C.thysanura* on boronia plant and its effect on the plant's growth(number of new nodes formed).

T1=Boronia plants infested with only *C.thysanura*; T2=plants infested with both *A.gossypii* and *C.thysanura*; T3=plants infested with only *A.gossypii*; and T4=uninfested boronia plants(control)

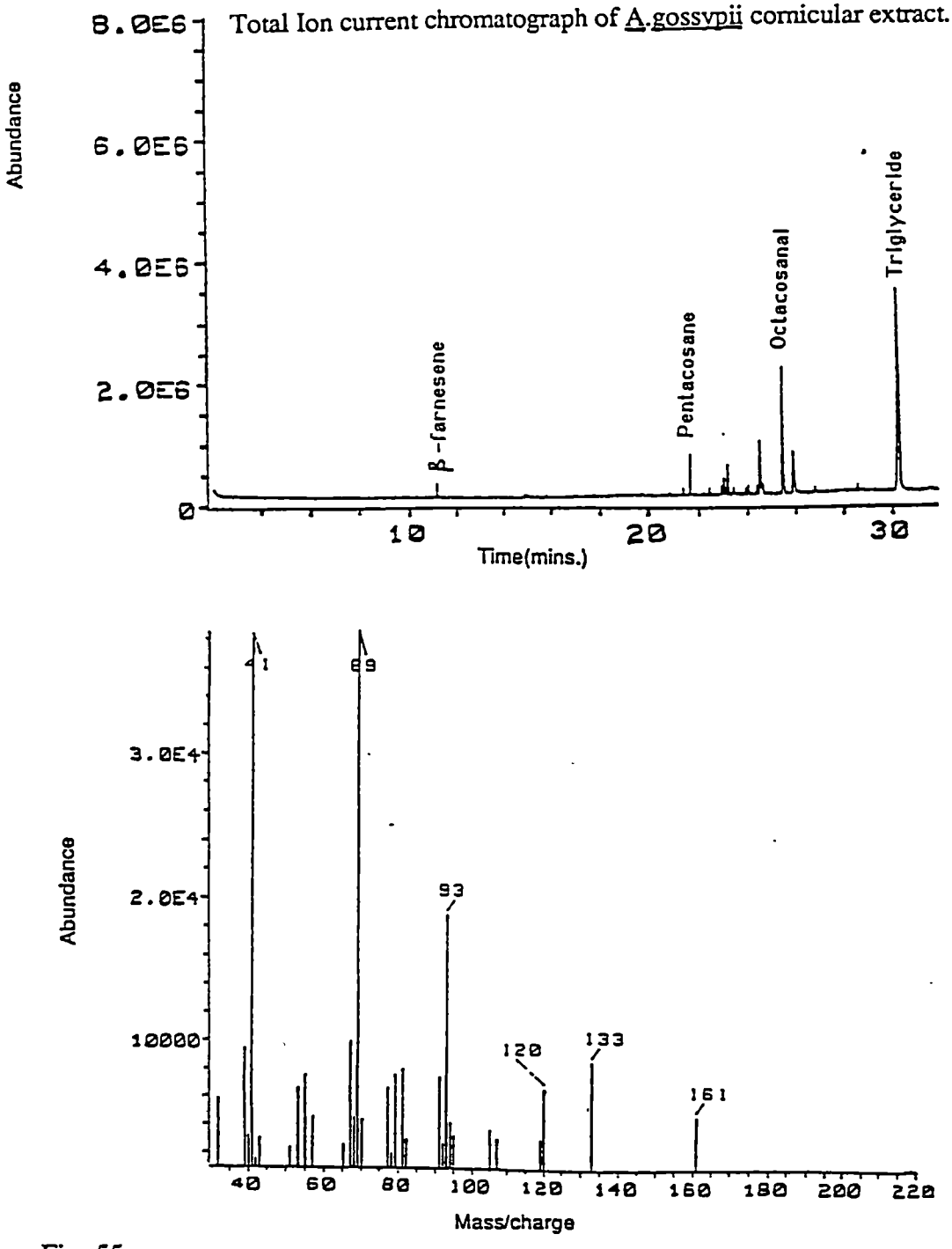


Fig. 55

Mass spectrum of - -farnesene from A.gossypii cornicular extract.

Table 49

The effect of *Aphis gossypii* on the oviposition of *C.thysanura* females on boronia plants.(Mean results of 5 replicates).

Treatments	No.of eggs laid/plant
1. Plants infested with both *A. gossypii* and *C.thysanura* females.	22.20a
2. Plants infested with only *C.thysanura*	133b

Lsd(0.05)=23.76; Lsd(0.01)=39.40

Means are significantly different P<0.01; Duncan's multiple range test.

3.5.5.2.3 Isolation and identification of the cornicular secretion of *A. gossypii*

The chemical released from the cornicles of *A. gossypii* was identified as trans-ß-farnesene. The total ion current chromatograph of cornicular extracts of *A. gossypii* and the mass spectrum of ß-farnesene from the cornicular extract are shown in Fig. 55.

4. Discussion

During the period of study, 1986-1989, *C. thysanura* occurred at pest densities in all study areas under observation until populations collapsed in the second generation of 1989 at both Copping and Kingston.

The analysis indicates that egg and first and second stage nymphal mortalities was caused by density related processes notably the predation by spiders. First and second stage nymphs are also attacked by microhymenoptera *Psyllaephagus* spp. Both sources of mortality acted in a delayed density dependent manner which, in turn, served as a negative feedback, with a delay of at least two generations, to regulate the psyllid

increase. In the absence of these agencies, control, but not regulation, can only be affected by intraspecific competition for food and space which is accompanied by severe damage to plant growth and yield performance.

Although the Varley and Gradwell test for proof of density dependence has been criticized on statistical grounds (Berryman 1981, Den Boer 1986, Manly 1989 etc), it still remains an important method which has a biological significance. Despite these criticisms the method is more realistic and understandable and pest control decisions can easily be made out of population data subjected to this analysis. It is therefore not surprising that though the population dynamics of most insects have been studied intensively, their control strategy has often failed and still remained a major problem for most crop plants as regulating mechanisms have not been adequately described.

Regressing k_{3-5} values (mortality of third to fifth instar due to parasitism) gave a relationship which was important in *C. thysanura* control because by reducing the numbers of third, fourth and fifth instar nymphs without affecting the parasitoid population (eg. by stem application of systemic insecticide) ensured effective parasitism through conservation of parasitoids and predators. This was the basis of the pest control strategy developed in this study.

At Copping, the *C. thysanura* population oscillated regularly with low amplitude due to the action of natural enemies from 1986 until the third generation of 1987, when the stabilising process failed due to the effects of monocrotophos insecticide spray drift from an adjacent commercial plot. Most of the natural enemies were killed, thus breaking the host-natural enemy synchrony, and this led to an increase in *C. thysanura* numbers in 1988. With the key mortality factors removed, psyllid numbers at Copping continued to increase during the summer and autumn/winter generations of 1988 to a level of 31.67 eggs and nymphs per terminal shoot. As host plant quality declined due to feeding by psyllid nymphs and adults, environmental opposition to population growth increased. The number of feeding and oviposition sites available on the severely damaged foliage was not enough to sustain the excessive number of progeny during that period. Therefore, competition for food and space set in. This led to emigration of some of the psyllid adults in the third generation of 1988 (after emerging from competing nymphs in the earlier generation of the same year) in search of new

feeding and oviposition sites. Following emigration, the *C. thysanura* population at Copping declined rapidly in 1989. The reasons for the decline and subsequent collapse of the population were (1) intraspecific competition resulting in small *C. thysanura* females with low fecundities, (2) poor condition of the host plant's foliage which, in addition to providing an inferior source of food, also reduced the quantity of available terminal shoots for oviposition, (3) attack of the host plant by the rust, *P. boroniae* , which caused the host plants to lose their tips and most of their leaves further reducing available oviposition sites, and (4) increased effectiveness of predators and parasitoids as psyllid numbers declined.

Nymphal mortality due to crowding was very low (ca. 20 per cent) and was not important in adjusting the population at Copping, but the effects due to intraspecific competition between the psyllids, both nymphs and adults, were more important in determining the decline of the population.

At Kingston, psyllid numbers peaked in 1987 in the second generation (15.30 eggs and nymphs per shoot) after which numbers declined and the population collapsed in the second generation of 1989. The decline in psyllid numbers was due to an ill timed insecticide spray against scale insects in the fifth and sixth generations. The insecticide spray could have resulted in a psyllid outbreak due to its effect on the natural enemies however the poor condition of the foliage as a result of rust infestation prevented it.

Apart from predators and parasitoids, *A.gossypii* infestation of boronia plants at Kingston could also have been a factor in the population decline in the 1989 second generation. The emigration of adult psyllids as a result of high aphid numbers reduced the number of eggs laid on the host plant and with fewer new nymphs hatching conditions again became favourable for high rates of predation and parasitism and the population collapsed during the second generation at Kingston.

Weather played only a limited role in the dynamics of *C. thysanura* eggs and nymphs due to the degree of protection afforded to the egg and nymphal stages by the leaf axils and flowers of the host plant. Warm weather rather than cold was, in general, more important as a mortality factor in eggs and early nymphal stages in Tasmania for in winter eggs and nymphs were protected and or physiologically adapted to survive.

Activity was low and weather conditions constant. In contrast the Tasmania summer is variable with large differences in temperature being experienced over short time intervals. Weather is unpredictable.

During the years of investigation, *C. thysanura* populations were found to be modified by such factors such as (1) quantity and quality of available food plants, (2) cultural practices including mortalities due to flower harvesting and pruning, (3) weather (5) presence of *A.gossypii*, (6) parasitoids and predators and (7) intraspecific competition affecting adult size and fecundity and emigration. The nature of each these factors was demonstrated by key factor analysis.

In the study by Clark (1962, 1963a,b, c, d; 1964a, b, c) of *C. albitextura* on *E. blakeyi*, psyllid numbers were determined also by the quantity and quality of the food plant, intraspecific competition, predators, parasitoids and weather. The conclusions to be drawn from this study are quite similar to those drawn from Clark's work. Both *C. thysanura* and *C. albitextura* , in the absence of the key regulatory factors, parasitism and predation, reached densities at which they destroyed the food plant, resulting in a significant decline in population. Clark (*loc. cit.*) reported that in *C. albitextura,* emigration was of minor importance compared with the effect of the reduction in egg fecundity at high densities, but with *C. thysanura,* both emigration and a reduced fecundity of adults which did not emigrate were important in reducing the population to lower levels.

Watmough (1968) also reported that emigration accompanied by reduced fecundity were major factors operating at high population densities of broom psyllids when predators failed to control the population.

C. thysanura populations are likely to remain low after outbreaks following the effects of intraspecific competition when the action of natural enemies can again regulate the population.

Though Clark, Geier, Hughes and Morrison (1967) criticised Milne's (1962) theory of regulation of natural populations, the functioning of the life system of *C. thysanura* developed through key factor analysis conforms to Milne's theory.

Chapter 6

Mechanism of resistance of *Boronia megastigma* to *C.thysanura* and the factor determining susceptibility or resistance of boronia cultivars to *C.thysanura* attack.

Introduction

Initial observations revealed that *C.thysanura* populations and the damage caused to the host plant differed markedly on different boronia cultivars. Differences in damage caused by an insect to different plants in a locality during a given period reflect the plants' relative susceptibility or resistance to insect attack. The extent of damage would differ acording to the density of the insect population established on the plant. According to Painter (1951), a plant showing "tolerance" to an insect is likely to suffer increased damage if the insect population infesting it exceeds a certain limit. On this basis, differences in relative susceptibility or resistance of different plants would be determined by factors influencing the establishment on them of either a large or small insect population.

C.thysanura prefers young shoots for feeding and oviposition. Using resistance categories of tolerance, antibiosis and antixenosis (which describes the plant properties responsible for non preference) (Kogan and Ortman 1978; Painter 1951), boronia cultivars were evaluated under glasshouse and field (natural) conditions to investigate the nature of resistance to the pest.

This section also investigates whether hardness of the terminal shoot of boronia cultivars is a factor in determinig susceptibility or resistance to *C.thysanura* attack.

2. Materials and Methods.

2.1 Source of Plant Materials.

The 23 boronia cultivars selected were; HC4, HC127, HC16, HC106, HC5,

HC122, HC9, HC17, HC11, HC28, HC129, HC223, HC132, HC6, HC7, HC27, HC136, HC130, HC131, HC134, HC14, HC142 and HC133.

These boronia cultivars were developed by The University of Tasmania's Horticultural Research Centre, and are distributed to Tasmanian boronia growers.

2.2 Field Study.

The 23 boronia cultivars were planted in a field at Kingston, South Tasmania in 1984. Each plot consisted of three rows, 0.5 m apart, and consisted of a total of 21 plants. The plants within each row were spaced 0.5 m apart. Assessment of *C.thysanura* populations commenced on 31 October, 1986 when the plants were two years old and approximately the same height. All cultivars were found to have been sprayed with 0.04% demeton-S-methyl against *C.thysanura* in May 1986, five months before the start of this study by a postgraduate student studying the nutrition of boronia on a plot adjacent to the study area. However, the boronia cultivars were heavily infested with psyllids when the current work started.

Samples were collected every 10 days from 1986-1988. Five terminal shoots were taken randomly from one of the number of plants of each cultivar on each sampling date and each shoot placed separately in a plastic bag (15 x16 cm).

Using two forceps, the leaf axils of each terminal shoot were opened up to the tip under a binocular microscope and the number of eggs, nymphal insects and adults were counted and recorded separately for each cultivar immediately samples arrived at the laboratory.

The data for eggs, nymphal stages and adults for each year was analyzed separately and mean numbers at each sampling date were separated by Duncan's multiple range test. This type of analysis enabled comparison of each cultivar's performance each year and an indication of the maintenance of that performance throughout the study period. This was important as all the cultivars were sprayed with a systemic insecticide five months before the start of the study and might have had different levels of chemical residue in their tissues which could affect psyllid polpulations, particularly during the 1986 assessments.

Assessment of damage to each cultivar, measured as the number of new nodes

formed per terminal shoot, commenced on 1 October 1987 and ended on 30 June 1988. In this assessment, five plants from each cultivar (one from each replicate) were randomly selected and a terminal shoot from each selected plant was tagged and marked with olympic yellow paint just beneath the terminal bud.

Records of the number of new nodes formed were taken every 10 days throughout the sampling period.

Analysis of variance was used to analyze the data and the means of the various cultivars compared by Duncan's multiple range test.

2.3 Glasshouse Studies

2.3.1 Sources of Plant Material.

Cuttings from the 23 boronia cultivars grown in the field at Kingston (2.1) were propagated in the glasshouse from 10 cm-long terminal shoots in April 1987 and grown in a mixture of 50 per cent vermiculite and 50 per cent eucalyptus bark compost, mixed with 10 gms Osmocote (10-2.6-10) and Iso butyl Di Urea (IBDU) (14-6.1-11.6) (a controlled release NPK fertilizer). The cuttings were then placed in a mist bed protected from wind in a polythene house maintained at a constant temperature of 20°C. After 16 weeks, the rooted cuttings were repotted in a mixture of soil containing grey-coarse sand and eucalyptus bark compost mixed with 5 gms Nitrophoska (15-4-12), a slow release NPK fertilizer, and placed in the glasshouse maintained at a temperature of 18-25°C, for six months.

2.3.2 Ovipositional Preference.

2.3.2.1 Free Choice Preference Test.

The "free" choice ovipositional preference of *C.thysanura* among boronia cultivars was measured by counting numbers of eggs laid by psyllids on each of the 23 cultivars. The experiment, conducted in the glasshouse commenced on 9 May 1988, when the boronia cultivars were 12 months old and approximately the same height.

A potted plant of each of the 23 boronia cultivars to be tested was placed in a cage (60 x 60 x 70 cm). The terminal shoots of each plant were pruned to 5 shoots before the start of the study.

100 pairs of 5-day old *C.thysanura* adults, obtained from a culture maintained in the same glasshouse were introduced into the cage.

This experiment was replicated five times. The plants were removed from the cages after 10 days and cleared of adult psyllids. The terminal shoots of each plant were removed and eggs containing nymphs, representing viable eggs, were counted under a binocular microscope. The test was analyzed as a randomized block design and the means separated by Duncan's multiple range test.

2.3.2.2. No Choice preference tests.

The "no choice" preference of *C.thysanura* among the 23 boronia cultivars was measured by egg production and adult survival. Egg production was studied on the basis of pre-oviposition period and the number of eggs produced on the different cultivars.

The experiment commenced in the glasshouse on 10 May 1988 using 12 month old boronia cultivars as previously described.

A pair of newly emerged *C.thysanura* adults was taken from a stock culture reared to maturity on boronia plants in the same glasshouse and placed on each potted boronia cultivar (with each plant thinned to five terminal shoots). The infested potted plants were enclosed in a plastic (bottle) cage. This was replicated five times for each plant variety.

A rectangular viewing hole (10 x 6 cm) covered with a fine cloth mesh, was cut in the wall of the plastic cage. Each plant was examined daily very closely with a 5 cm hand lens for eggs in the leaf axils of the terminal shoots without disturbing the adult psyllids. The time that elapsed before the female psyllid laid eggs was recorded as the pre-oviposition period. The time when each psyllid died was recorded and this represented longevity or adult survival period on the various cultivars.

When the adults on all infested plants died, the plants were taken to the laboratory

and the total number of eggs and nymphs present on each plant was counted, thus giving the total number of viable eggs produced by the female during its life. The data was analyzed as randomised block design and the mean number of viable eggs per female on each variety was compared by Duncan's multiple range test.

2.3.3. Antibiosis studies.

2.3.3.1 Feeding and growth studies.

In this study, a pair of 6-day old male and female *C.thysanura* adults was taken from a culture in the glasshouse and caged in plastic bottle cages on each of the 23 boronia cultivars. After 24 h, all psyllids were removed from the test plants and eggs laid were counted; four eggs were left on each test plant and the remainder of the eggs were destroyed. This was replicated 5 times in the glasshouse.

After 10 days, eggs were examined for nymphal development and aborted eggs, but, in this case, all eggs hatched giving four nymphs per test plant. The plants were again enclosed in plastic bottle cages and examined regularly from the outside with a 5 cm hand lens until adult psyllids emerged.

Records were taken of the ability of the psyllid nymphs to moult and metamorphose on the various cultivars which was determined by (a) the percentage of individuals transforming into adults (nymphal survivorship) and (b) the average period required to do so. The ratio of (a) to (b), which represented the "growth index", i.e. the capacity of the insect to moult and metamorphose to adult, was also calculated.

Head capsule widths of five newly-emerged males and females from each replicate were measured. The data was analyzed as a randomised complete block design and the means separated by Duncan's multiple range test.

2.4. Hardness of the host plant as a factor in determining the degree of susceptibility and or resistance to *C.thysanura* attack.

2.4.1. Oviposition in relation to terminal shoot hardness of the host plant.

These studies were conducted in October 1988 in the glasshouse maintained at 18-20°C and 65 - 75% R H with psyllids from a glasshouse stock culture reared on HC4 boronia cultivar. Only 6-day old *C.thysanura* adult females, which were ready to oviposit, were used and males were provided for the duration of the experiment. The test plants were the 23 boronia cultivars propagated by cuttings in the glasshouse and were 18 months old and of the same size. Each test plant was thinned to five terminal shoots.

In this study, 60 male and female psyllids were confined in a cage (60 x 60 x 70 cm) containing each of the 23 potted boronia cultivars. This was replicated four times in similar cages in the same glasshouse. Records were taken of the number of eggs laid per terminal shoot on each test plant after 10 days.

2.4.2. Hardness of host plant terminal shoots.

After the eggs had been counted in 2.4.1., the hardness of the terminal shoots (top 10 cm) of the test plants was measured using a needle penetrometer after the type described by Prat (1934) and Pollard (1971). In this case, however, a metal needle holder was fixed in a tube by a screw and a 0.254 mm pin poised above a hole in a square metal block placed on an electronic balance (Mettler PM4600). The penetrometer thus had an electronic balance base which could be adjusted to zero at the start of any measurement. In operation, the test material (terminal shoot) was placed on the square metal block on the balance and held in position by two clips and the needle lowered steadily with the aid of a small handle connected to the needle holder by an elastic spring. Absolute hardness measurements (grams weight required for the penetrometer pin to puncture the leaf node) were taken at four penetrations between the second and fourth nodes of the terminal shoot of each cultivar and the mean absolute hardness taken for each terminal shoot. Absolute hardness of four terminal shoots from

each cultivar was taken in this way and recorded.

In addition, the thickness of the terminal shoot of each cultivar was measured with a microscope micrometer eye piece and recorded.

Relative terminal shoot hardness per millimeter shoot thickness (g/mm) was calculated from the data on absolute hardness and shoot thickness. All tests were analyzed separately as randomized complete block designs and the means separated by Duncan's multiple range test. A relationship was also established between the number of eggs laid per terminal shoot of each cultivar and the respective relative hardness of their terminal shoots. The slope of the resulting curve was tested against a slope of b=O.

In another study, four terminal shoots from each of the 23 boronia cultivars were collected in January 1989 and the mean absolute hardness (g) and terminal shoot thickness (mm) were measured using the same equipment and procedure in the laboratory.

The data were analyzed separately as randomised block designs and the means compared by Duncan's multiple range test. A relationship was also established between the relative hardness of the terminal shoots of the glasshouse test plants and the test plants grown in the field. The slope of the resulting curve was tested against a slope b=O.

3. Results and Observation.

3.1. Field Study.

Under field conditions, feeding damage by *C.thysanura* varied significantly (P<O.01) among the 23 boronia cultivars tested (Table 50). HC142, HC4, and HC 16 had the highest growth damage (least number of new nodes formed) compared with other cultivars; HC223 had significantly lower damage than other cultivars (except HC17 and HC136).

Significant differences (P<O.01) in mean adult psyllid populations were also detected among boronia cultivars in 1986, 1987 and 1988 (Table 51). HC16 had

Table 50

Mean number of new nodes formed per terminal shoot on 23 boronia cultivars grown under field conditions with natural infestations of *C.thysanura* during the 1987-88 season at Kingston, Southern Tasmania.

Boronia cultivar	Mean no.of new nodes/terminal shoot
6	0.75
11	0.68
131	0.53
9	0.90
134	0.68
7	0.58
122	0.78
4	0.43
130	0.68
223	1.00
133	0.85
5	0.75
136	0.95
132	0.63
27	0.63
17	0.98
129	0.55
106	0.85
16	0.40
28	0.65
127	0.45
142	0.39
14	0.83
Lsd(0.05)	0.05
Lsd(0.01)	0.07

Table 51

Mean number of adults per terminal shoot on 23 boronia cultivars grown under field conditions with natural infestations of *C.thysanura*,1986-88, at Kingston,Southern Tasmania.

Boronia cultivar	No.of adults/terminal shoot/sample date		
	1986	1987	1988
6	0.43	0.23	0.21
11	0.03	0.26	0.14
131	0.31	0.38	0.13
9	0.06	0.30	0.13
134	0.20	0.24	0.22
7	0.03	0.19	0.14
122	0.09	0.22	0.28
4	0.37	0.39	0.23
130	0.17	0.18	0.16
223	0.06	0.24	0.16
133	0.03	0.30	0.06
5	0.06	0.11	0.12
136	0.03	0.15	0.10
132	0.23	0.29	0.27
27	0.09	0.11	0.11
17	0.09	0.13	0.14
129	0.21	0.29	0.34
106	0.14	0.16	0.21
16	0.50	0.43	0.67
28	0.29	0.34	0.41
127	0.11	0.31	0.47
142	0.14	0.29	0.70
14	0.17	0.10	0.36
Lsd(0.05)	0.01	0.01	0.01
Lsd(0.01)	0.02	0.02	0.02

higher adult populations in 1986 and 1987 than did HC142 and HC4, but in 1988, the highest adult population was recorded on HC142. HC27 had the lowest number of adults per terminal shoot compared with other cultivars throughout the study period.

Significant differences (P<O.01) were also detected in the numbers of eggs laid on each cultivar (Table 52), HC142 having the highest and HC27 the lowest number of eggs, respectively. *C.thysanura* showed ovipositional non-preference for cultivar HC27. During the 1988 season, approximately three times more eggs were laid on HC142 compared with HC27.

Nymphal counts followed similar trends to egg counts, differing significantly (P<O.01) among cultivars (Table 53), with HC142 having the highest number of *C.thysanura* nymphs per terminal shoot, followed by HC4 and HC16. HC27 had the lowest nymphal population compared with other cultivars (except HC7) during the 1988 season.

3.2. Glasshouse Studies.

3.2.1. Ovipositional Preferences.

Significant differences (P<O.01) in ovipositional preferences were found among boronia cultivars under free choice conditions (Table 54). HC27 had significantly (P<O.05) lower egg counts than did the other cultivars (except HC136). HC142 had significantly (P<O.01) the highest number of eggs (445.80 per plant), followed by HC4 (282.6 eggs per plant).

Under no-choice conditions there were significant diufferences (P<O.01) in numbers of eggs produced per female caged on each cultivar (Table 55). Maximum numbers of eggs were laid per female on HC142 and HC4 and minimum on HC27. Under the no-choice condition, eggs laid on HC27 were crowded on the terminal bud and the first node below it, but eggs laid on HC142 and HC4 plants were spread in the leaf axils of the eight nodes below the terminal bud, the fourth node's containing the

Table 52

Mean number of eggs per terminal shoot on 23 boronia cultivars grown under field conditions with natural infestations of *C.thysanura*,1986-88 at Kingston, South Tasmania.

Boronia cultivars	No.of eggs/terminal shoot/sample date		
	1986	1987	1988
6	8.90	8.76	9.60
11	4.29	7.94	10.82
131	9.97	10.22	11.38
9	4.09	8.39	8.95
134	10.40	11.07	11.69
7	6.86	7.02	10.22
122	7.20	9.13	10.28
4	9.51	8.99	12.76
130	8.09	9.70	9.94
223	8.34	9.04	12.50
133	6.03	9.38	11.50
5	5.06	7.73	10.02
136	5.14	6.96	7.51
132	6.69	9.33	14.97
27	4.29	5. 84	6.91
129	9.37	9.59	10.40
106	6.34	7.96	12.06
16	14.71	15.40	15.48
28	6.92	6.94	14.83
127	8.72	9.86	12.64
142	8.24	15.07	20.95
14	5.17	8.41	11.94
Lsd(0.05)	0.23	0.04	0.09
Lsd(0.01)	0.30	0.06	0.12

Table 53

Mean number of *C.thysanura* nymphs per terminal shoot on 23 boronia cultivars grown under field conditions with natural infestations of *C.thysanura*, 1986-88, at Kingston.

Boronia cultivar	No of nymphs/terminal shoot/sample date		
	1986	1987	1988
6	3.43	5.98	6.98
11	1.14	7.20	9.95
131	7.77	9.76	10.93
9	4.14	6.02	7.26
134	3.87	7.42	9.80
7	1.34	3.04	3.48
122	2.46	6.88	9.04
4	9.77	9.90	12.39
130	1.66	4.33	8.00
223	1.94	6.44	7.69
133	3.11	7.73	7.95
5	0.60	4.22	7.78
136	2.21	4.72	4.74
132	3.57	8.46	12.16
27	0.71	2.1	4.58
17	1.86	3.32	6.37
129	3.86	6.89	7.08
106	1.71	4.26	7.31
16	5.18	9.86	15.02
28	7.09	9.02	14.02
127	2.88	9.31	11.80
142	9.27	13.49	21.87
14	5.53	7.53	13.42
Lsd(0.05)	0.04	0.06	0.03
Lsd(0.01)	0.06	0.08	0.04

Table 54

Free choice tests for ovipositional preferences of *C.thysanura* on boronia cultivars after 10 days of infestation.

Boronia cultivars	No.of eggs/plant
4	282.60
127	123.20
16	195.00
106	80.80
5	65.40
122	174.00
9	103.40
17	119.00
11	262.00
28	80.20
129	161.20
223	148.40
132	245.40
6	217.80
7	180.40
27	8.40
136	39.60
130	116.60
131	198.00
134	142.20
14	180.40
142	345.80
133	179.80
Lsd(0.05)	57.01
Lsd(0.01)	74.92

Table 55

No choice tests for longevity and egg production in *C.thysanura* females on different boronia cultivars.

Boronia cultivars	Longevity (days)	Preoviposition period (days)	No.of eggs per female
4	24.60	5.80	90.00
127	24.00	5.80	84.20
16	24.20	5.60	76.00
106	24.40	6.00	45.00
5	24.60	5.60	56.00
122	24.20	6.00	86.00
9	24.40	6.20	45.00
17	24.60	5.80	66.00
11	24.00	5.60	62.00
28	23.80	6.00	42.00
129	24.80	6.00	78.00
223	24.60	6.20	68.00
132	23.60	5.60	78.00
6	23.80	5.60	45.00
7	23.80	6.00	76.00
27	23.60	6.00	23.00
136	24.60	6.20	46.00
130	23.20	5.80	58.20
131	23.60	6.00	77.00
134	23.80	5.80	82.00
14	23.60	5.80	75.00
142	24.60	5.80	93.00
133	24.40	5.60	50.00
Lsd(0.05)	2.06	0.62	19.45
Lsd(0.01)	2.73	0.82	25.56

No significant differences ($P>0.05$) were detected in the preoviposition periods and the female longevity; however, the number of eggs per female differs significantly ($P<0.01$).

highest numnber of eggs.

No significant differences (P>O.05) were detected in the pre-oviposition periods of psyllids kept on different cultivars (Table 55), all psyllids having a mean pre-oviposition period of 5.87 days.

There was also no significant difference (P>O.05) in survival period or longevity of female psyllids kept on different cultivars, indicating that psyllids could survive equally on all cultivars (Table 55).

3.2.2. Antibiosis Effect.

No significant antibiosis effect (P>O.05) was detected between cultivars for nymphal survivorship to adult, developmental time from oviposition to adult or the size of emerging adults (Table 56). Nymphal survivorship varied from 92-96 per cent in the glasshouse. The average duration of the developmental period was 40.52 days. The growth index, which indicates the ability of psyllid nymphs to moult and metamorphose, showed no significant differences between boronia cultivars (P>O.05) and ranged from 2.26 to 2.40 between cultivars (Table 56).

3.2.3. Host plant terminal shoot hardness.

The mean absolute hardness, mean thickness and mean relative hardness of the terminal shoots of the 23 boronia cultivars attacked by *C.thysanura* are shown in Table 57. Analysis showed significant differences (P<O.01) among cultivars in terminal shoot hardness measurements of the leaf nodes and thickness measurements of the terminal shoots (Table 57). In all cases, terminal shoots of HC27 were significantly harder (P<O.01) in both absolute and relative terms; terminal shoots of HC142 and HC4 were significantly softer (P<O.01); and terminal shoots of HC27 and HC6 were consistently thinner (P<O.05) than other cultivars, respectively (Table 57). HC142 had thicker terminal shoots than other cultivars, although not differing significantly from terminal shoots of HC4, HC223, HC106, HC132 and HC14 (P>O.05) (Table 57).

A positive correlation was established between the relative hardness of the

Table 56

Antibiosis studies for *C.thysanura* nymphal survivorship, developmental time from oviposition to adult, growth index and the size of emerging adults (n=10) on 23 boronia cultivars.

Boronia cultivars	Survivorship (per cent)	Developmental time(days)	Growth index	Width of head capsule (mm)	
				male	female
4	96	40.48	2.37	0.43	0.46
127	94	40.86	2.30	0.42	0.46
16	96	40.81	2.35	0.41	0.48
106	96	40.35	2.23	0.42	0.47
5	94	40.35	2.33	0.40	0.46
122	96	40.46	2.37	0.40	0.47
9	96	40.46	2.37	0.42	0.46
17	98	40.76	2.40	0.43	0.46
11	96	40.46	2.37	0.43	0.48
28	96	40.52	2.37	0.40	0.47
129	98	40.76	2.40	0.42	0.46
223	94	40.70	2.31	0.43	0.48
132	96	40.00	2.40	0.42	0.46
6	92	40.72	2.26	0.41	0.46
7	94	40.41	2.33	0.43	0.47
27	92	40.41	2.28	0.41	0.46
136	94	40.68	2.31	0.41	0.47
130	92	40.64	2.26	0.43	0.47
131	92	40.76	2.26	0.41	0.47
134	96	40.52	2.37	0.40	0.46
14	94	40.40	2.33	0.43	0.46
142	98	40.11	2.39	0.42	0.46
133	96	40.58	2.37	0.43	0.47
Lsd(0.05)	7.46	0.75	0.17	0.03	0.02
Lsd(0.01)	9.80	0.99	0.23	0.04	0.03

No significant differences (P>0.05) were detected.

Table 57

Mean absolute hardness, terminal shoot thickness and mean relative hardness measurements for the terminal shoots of 23 boronia cultivars using a 0.254 mm diameter pin in the glasshouse.

Boronia cultivars	Mean absolute hardness (g)	Mean terminal shoot thickness (mm)	Mean relative hardness (g/mm)
5	37.32	0.70	53.73
136	38.97	0.66	58.86
223	42.23	0.79	53.67
130	44.51	0.65	68.48
133	28.57	0.71	40.13
4	20.71	0.78	26.75
127	30.22	0.65	46.64
16	32.46	0.71	45.60
106	43.79	0.78	56.56
122	35.26	0.69	51.34
9	40.00	0.63	49.68
17	27.11	0.71	38.26
11	26.87	0.70	38.39
28	30.36	0.69	44.21
129	28.42	0.75	38.07
132	24.76	0.78	31.97
6	26.65	0.60	44.42
7	33.19	0.76	44.03
27	68.57	0.60	114.29
131	29.18	0.64	45.94
134	33.23	0.66	50.40
14	44.78	0.79	56.91
142	19.00	0.83	23.13
Lsd(0.05)	0.87	0.06	4.03
Lsd(0.01)	1.14	0.08	5.30

terminal shoots of the various cultivars grown in the field and in the glasshouse, with the height of the resulting curve being highly significant (P<O.001) above the X-axis (Fig. 56). HC27 continued to be the "hardest" and HC142 the "softest" of the cultivars in the field (Fig. 56). The implications of the relative hardness of the terminal shoots of host plant cultivars to the ovipositional responses of *C.thysanura* are found in the discussion.

3.2.4. Oviposition in relation to terminal shoot hardness.

The results of experiments in which *C.thysanura* females were given a choice of the 23 boronia cultivars of varying relative hardness (5 replicates) are shown in Table 58. The results indicated that the number of eggs laid per terminal shoot among the boronia cultivars differed significantly (P<O.01) (Table 58). The greatest number of eggs per terminal shoot after 10 days were laid on HC142 and HC4 which had the softest terminal shoots among the cultivars; the lowest number of eggs (1.04) per terminal shoot was laid on HC27, the cultivar with the hardest terminal shoot (114.29 g/mm) (Table 58). From the results of the "no choice" experiments where female psyllids were caged on the various cultivars in plastic bottle cages (Table 55) female psyllids kept on HC27 laid an average of 23 eggs during a lifespan of 23.60 days, whereas female psyllids kept on varieties HC142 and HC4, which had soft terminal shoots, laid an average of 93.00 and 90.00 eggs, respectively, during adult life.

A relationship established between relative hardness of the terminal shoots of the cultivars and the number of eggs laid per terminal shoot on the cultivars in both "free" and "no" choice ovipositional preference tests indicated that the number of eggs laid per terminal shoot decreased with increasing terminal shoot hardness and this was significant (P<O.001) in both tests (Fig. 57). The negative correlation between oviposition and relative hardness of terminal shoots indicated that female psyllids show an ovipositional preference for softer terminal shoots. Fewer eggs were laid when the relative hardness of the terminal shoot exceeded 80 g/mm (Fig 57). In all cases, however, the relative hardness of terminal shoots of cultivars presented for glasshouse studies were concentrated in the range of 20 to 70 g/mm except HC27 which had a

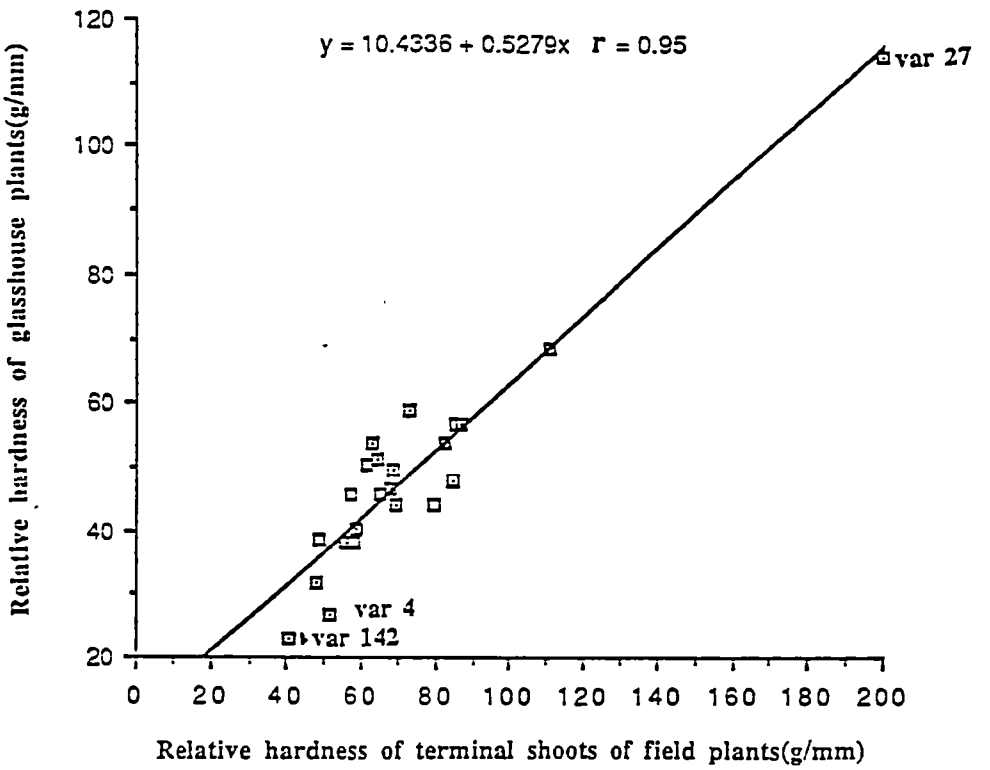


Fig. 56

Relationship between the relative hardness(g/mm) of the terminal shoots of 23 boronia cultivars grown under glasshouse and field conditions.

Table 58

The effect of relative hardness of the terminal shoots of boronia cultivars on the oviposition of *C.thysanura* in the glasshouse. (Results of a free choice tests).

Boronia cultivars	Relative hardness g/mm	No.of eggs/terminal shoot
4	26.75	16.32
127	46.64	14.62
16	45.60	13.70
106	56.56	7.68
5	53.73	10.24
122	51.34	14.34
9	49.68	7.10
17	38.26	11.54
11	38.39	11.26
28	44.21	7.00
129	38.07	13.42
223	53.67	10.86
132	31.97	14.14
6	44.42	8.58
7	44.03	12.54
27	114.29	1.04
136	58.86	7.30
130	68.48	9.02
131	45.94	12.82
134	50.40	14.14
14	56.91	12.92
142	23.13	16.06
133	40.13	9.26
Lsd(0.05)	4.03	3.81
Lsd(0.01)	5.30	5.01

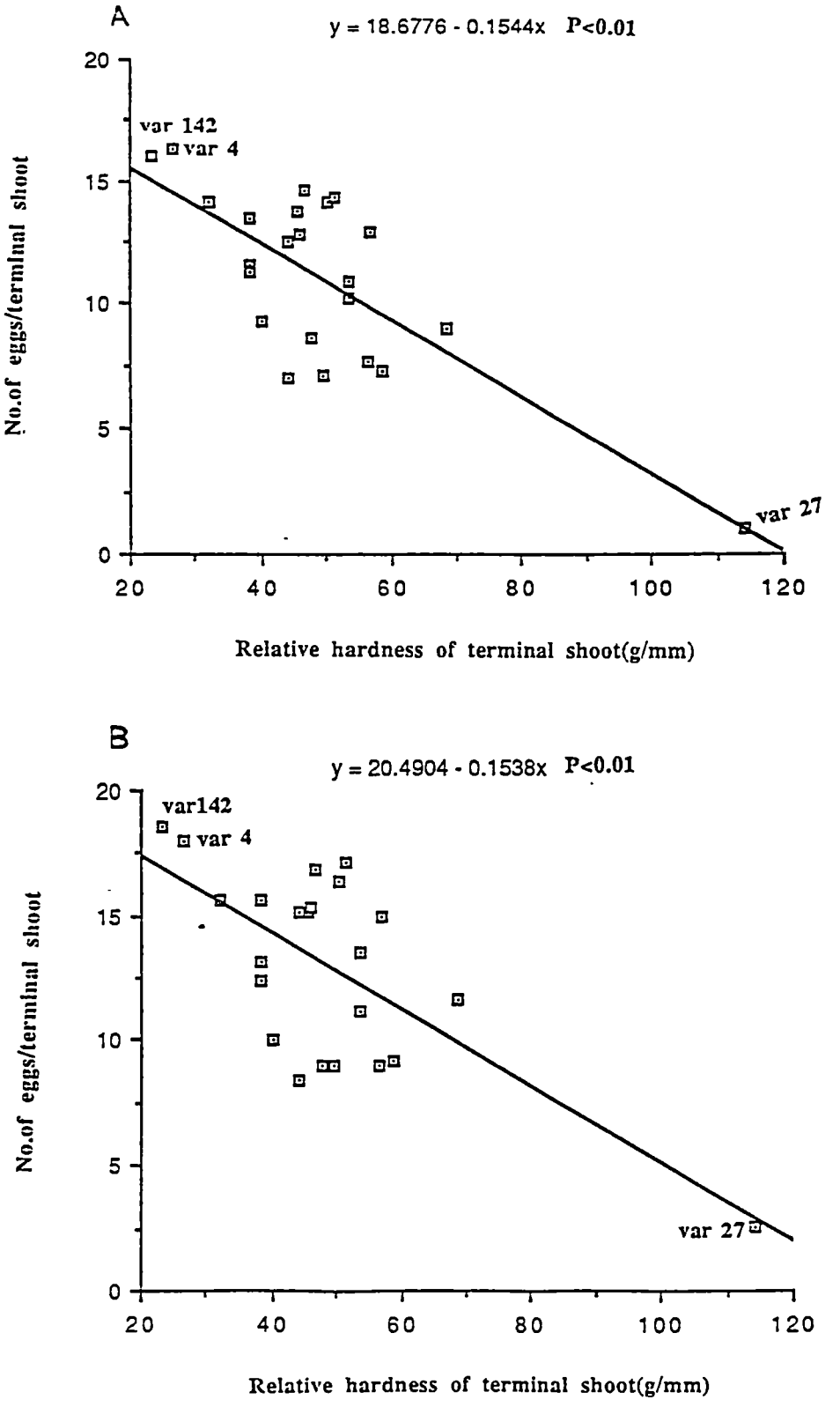


Fig. 57

Number of eggs of *C.thysanura* laid on 23 boronia cultivars in (A)"free choice" and (B)"no choice" tests in the glasshouse, plotted against the relative hardness (g/mm) of the respective cultivars.

relative hardness of 114.29 g/mm.

It was observed that HC27 (the hardest cultivar) had "open" terminal shoots i.e. the leaflets extended laterally from the terminal shoots exposing the leaf axils, except for the node just below the terminal bud and also poor growth. Under both field and glasshouse conditions, eggs were laid mostly on the first node and the tip of the terminal shoot of HC27. The softer cultivars, HC4 and HC142 had "closed" terminal shoots i.e. the leaflets extended parallel to the stem of the terminal shoot forming an envelope that enclosed the leaf axil. This type of plant characteristic did not expose the leaf axils or the stem of the terminal shoots, thus offering protection for the psyllids. On softer plants, *C.thysanura* eggs were laid in a greater number of leaf axils below the tip of the terminal shoot.

4. Discussion.

The mechanism of resistance in *B.megastigma* cultivars according to the results presented in this study is antixenosis/non-preference to *C.thysanura* oviposition. This may explain the observation that certain boronia cultivars had a lower psyllid population in the field than would otherwise have been expected on tolerant cultivars.

Under both glasshouse (free and no-choice trials) and field conditions, HC27 was less preferred for *C.thysanura* oviposition than were the susceptible HC142, HC4 and HC16 cultivars.

Free choice ovipositional non preference of psyllids has been reported by other workers including Wilde and Van Schoonhoven (1976), Moran (1968) and Kornegay, Cardona and Van Schoonhoven (1986). Ovipositional non preference, even under no choice conditions as detected in *C.thysanura* when psyllids were forced to feed and oviposit on a particular boronia cultivar, had been reported by Wilde and Van Schoonhoven (1976) for *E. kraemeri* on *Phaseolis vulgaris* (L.) in Brazil.

The results of this study again indicated that relative hardness of terminal shoots was the plant physical factor which determined the discrimination by ovipositing female psyllids for egg disposition among boronia cultivars. Pollard (1971), in his study of the action of hemipteran mouthparts in relation to hardness of plant and

polyporus tissues using a 0.254 mm diameter needle-type penetrometer, measured and expressed "hardness" in terms of weight required to effect penetration for a unit distance (g/mm) and emphasised that hardness tests give relative, and not absolute, results. However, he stressed that a number of factors, such as elasticity, plasticity, toughness and tenacity, as well as hardness, are the complex of physical factors involved in host plant selection and choice by hemipterans.

In both glasshouse and field studies, psyllids discriminated against HC27 (the hardest cultivar) for oviposition. The choice of HC142 and HC4 (the softest cultivars) by ovipositing *C.thysanura* females was important for at least two reasons. Firstly, softer terminal shoots enable easier penetration of the egg stalk into the leaf axil tissue which was important for egg survival (White 1968; Blowers and Moran 1967; Takara *et al.* 1986). Secondly, the "closeness" of the softer terminal shoot offered protection for *C.thysanura* eggs and nymphs against environmental factors such as wind. The "openness" of the terminal shoot, a characteristic of hard cultivars (eg. cultivar HC27) exposed the eggs in the leaf axils to the enviromental factors.

Although the selection by *C.thysanura* adults of host plants with softer terminal shoots depends on a number of complex responses including some physiological factors, once the insect had made this choice the final selection of oviposition sites depends mainly on physical factors. After arrival on the host plant, *C.thysanura* females commence to feed before wandering about slowly from leaf axil to leaf axil, stopping at leaf nodes to insert the ovipositor and test the leaf axil surface. The insertion of the ovipositor in the leaf axil during oviposition produces a hole in the leaf axil into which the egg pedicel is forced as the egg is laid.

In the light of this ovipositional behaviour and the fact that *C.thysanura* females could restrain oviposition on relatively harder shoots in this study (Table 55), the greater number of eggs laid on softer terminal shoots (HC142 and HC4) compared with hardest shoots (HC27) can be explained as a response to terminal shoot hardness. Morphological or physical characteristics of host plants are known in some instances to protect the host plant from insect attack. Sorensson and Brewbaker (1984) reported that *H.cubana* does not oviposit on *Leucaena* varieties that have more hairs on the shoot.

There is also a strong evidence by Watmough (1968a) and Catling, (1969a) that younger, and more vigorous plants support higher psyllid population than do older plants and Kogan (1974) reported that certain morphological characters of the host plant such as toughness, pilosity and the presence of thorns or spines could act as barriers to normal insect feeding and oviposition. This study, however supports the findings of Moran (1968) and Moran and Buchan (1975) who reported that *T.erytreae* show ovipositional preference for younger and softer citrus leaves. Furthermore, Moran and Buchan (loc.cit) reported that *T.erytreae* did not lay eggs on citrus leaves exceeding a hardness rating of 90 g/mm lamina thickness. But in *C.thysanura* fewer eggs were laid on terminal shoots of hardness exceeding 80g/mm.

Clark (1963a), in his work on factors affecting the attractiveness of foliage for oviposition by *C.albitextura*, concluded that besides leaf age, position of leaf on the growing shoot and nutritional status, oviposition by *C.albitextura* was also influenced by the degree of psyllid infestation of the leaves and the presence or absence of psyllid eggs on the host plant leaves. He said that the presence of eggs tends strongly to attract further oviposition in proportion to the number of eggs already laid on the leaf.

In this study, it has been found that, for *C.thysanura*, the presence of eggs in leaf axils of boronia plants did not necessarily attract further ovipositions by female psyllids as they tend to spread their eggs in an attempt to prevent overcrowding which could lead to intraspecific competition for feeding and oviposition sites during the nymphal and adult stages. However, in addition to the factors carefully outlined by Clark (1963a), varying terminal shoot relative hardness, coupled with the "closeness" or "openess" of the terminal shoot of the host plant, are factors which could determine the attractiveness of that plant for oviposition by *C.thysanura* and the number of eggs laid per female.

No antibiosis effect was detected when nymphal mortality, developmental time, growth index and the size of newly emerged adults were measured suggesting that irrespective of hardness differences among cultivars, *C.thysanura* nymphs could survive equally on all host plants. The survival of *C.thysanura* nymphs on the harder cultivar (HC27) is made possible by the glueing together of leaflets on the first and second nodes below the terminal bud into an envelope by honey dew produced by the

nymphs, thus protecting them from environmental effects while feeding at the tip of the terminal shoot and the first node.

No cultivar was found to tolerate *C.thysanura* attack. HC223, which had the lowest growth damage in the field (Table 50), could not be said to tolerate psyllid attack as the mean number of psyllids per terminal shoot recorded on this cultivar during the study period in the field was less than the economic injury level.

Because *C.thysanura* has been recorded only on *B. megastigma* in Tasmania, and psyllid numbers were low on cultivars which had relatively harder terminal shoots, and were less attractive for oviposition, the commercial growth of these cultivars may cause the psyllids to seek out other hosts, thereby reducing their populations and subsequent feeding damage in boronia fields.

Chapter 7

Development and Application of an Integrated Pest Management Programme for *C. thysanura*

1. Introduction

Demand for boronia oil in the 1980's led to an increase in the number of boronia plantations in Tasmania. However, infestation by *C. thysanura* significantly affected flower and oil production.

Before the start of this study, boronia growers were spraying crops 10-12 times a year with demeton-S-methyl to control this pest, but without success. The frequent outbreaks of the pest demanded the development of a control programme which was effective and ecologically sound.

This section investigates the development of an IPM programme based on fewer applications of a systemic insecticide, applied at low dosage, using an efficient method of application timed to conserve beneficial insects while ensuring a residue-free boronia oil. In addition, cultural methods of control and the use of resistant plant cultivars were considered.

Also reported in this section are comparisons of flower and oil yields and the control economics of commercial boronia crops receiving conventional chemical and IPM programmes.

2. Materials and methods

2.1 Study areas

The major part of this study was conducted on a 4 ha boronia farm at Copping (eastern Tasmania) with additional large scale insecticide field trials at Huonville (southern Tasmania) and Bakers Beach (north-western Tasmania). The boronia plants at Huonville and Bakers Beach were three years old and of similar height and planted in rows at 0.5 m spacing with 1 m between rows.

2.2 Systemic insecticides tested

The systemic insecticides evaluated were Metasystox 25 EC (demeton-S-methyl, Bayer Australia Ltd.); Rogor 30 EC (dimethoate, May and Baker Rural Australia Pty. Ltd.); Nuvacron 40 EC (monocrotophos, Ceiba Geigy Australia Ltd.); and Phosdrin 36 EC (mevinphos, Shell Australia Ltd.). The recommended dosages for insecticides in terms of per cent active ingredient (a.i.) were 0.03 (demeton-S-methyl), 0.04 (dimethoate), 0.04 (monocrotophos) and 0.03 (mevinphos).

2.3 Glasshouse spray test

2.3.1 Selection of appropriate systemic insecticide

The aims of this trial were to determine (1) the minimum effective dosage for *C. thysanura* control and (2) the time taken for boronia plants to completely absorb the insecticide spray.

The method devised by Lindquist, Bull and Ridgway (1965) for testing systemic insecticides was used to evaluate the four insecticides at 0.01, 0.02, 0.03 and 0.04 per cent v/v, respectively. The boronia plants were potted 12 month old HC4 cultivar plants selected from stock. Each treatment was replicated 10 times and, for each treatment, the stem and four basal leaves of each plant were sprayed to run off using a knapsack sprayer delivering 420 ml/min. Each side of the plant was sprayed for two seconds. Immediately after treatment application, the terminal tips of each plant were infested with five newly emerged 5th stage nymphs selected from the culture cage. All nymphs were starved for 24 h prior to the experiment. A fifth series of replicate plants were sprayed with water. Plastic bottle cages were established over each plant. Records were taken daily of the number of dead nymphs on each treated plant until all insects died. The mortalities for each treatment were calculated on a daily basis to determine treatment mortalities.

2.4 Field trials

2.4.1 Determination of the most effective application method

A small scale trial was conducted to (1) determine the best site to apply systemic

insecticides to boronia plants and obtain minimal or no effect on *C. thysanura* parasitoids while controlling the psyllids and (2) confirm in the field the efficacy of the lowest dosage assessed in the glasshouse trials.

The experiment was commenced at Copping on December 23 1986. Each of the four insecticides was evaluated by spraying either the foliage (FS) or the stem (SS) of boronia plants at 0.02% a.i. Each treated plot was 3 m wide and 10 m long and consisted of 20 boronia plants. Treatment applications were arranged in a randomised block design with seven replicates. A 4m guard row separated each replicate to minimise any insecticide drift. Each insecticide was applied from a knapsack sprayer at the rate of 420 ml toxicant per minute.

In the stem sprayed plots, the green stems were sprayed for five seconds on both sides leaving the foliage unsprayed. A control plot was set up with the plants left unsprayed. The application was repeated 28 days later towards the end of the *C. thysanura* generation. At that time, fourth and fifth stage nymphs formed about 85 per cent of the psyllid population and parasitoids, which had attacked *C. thysanura* nymphs earlier, had pupated in the host mummy.

Counts of psyllid nymphs were made by examining 70 randomly selected terminal shoots, 15 cm long, from each treatment (i.e., 10 terminal shoots/replicate) under a binocular microscope. Records were taken of the number of live nymphs and mummified nymphs. The mummies from each treated plot were kept separately in the glasshouse and records taken of parasitoids that emerged.

Pretreatment counts were made 24 h before initial treatment and post-treatment counts taken after 3, 7, 14, 21, 28, 35, 42, 49 and 56 days. The 28 days post-treatment count formed a pretreatment count for the second application in January. The growth of the plants in each treated plot was assessed from 10 plants randomly selected from each treated plot (one plant from replicates 1, 2, 3 and 4, and two plants from replicates 5, 6 and 7) and a dominant terminal shoot from each plant tagged; the tip of the terminal shoot was marked with waterproof yellow paint (Dulux Australia Pty. Ltd.). Records were taken of the number of new nodes formed at weekly intervals for eight weeks.

2.4.2 Evaluation of chemical spray followed by pruning of terminal shoots of boronia plants on *C. thysanura* populations.

The aims of this experiment were to (1) determine the effect of chemical spray (SS or FS) followed by pruning of the dominant terminal shoots of boronia plants on psyllid and parasitoid populations and (2) compare chemical plus cultural treatment with chemical treatment alone to assess which was the most effective control method which conserved parasitoids. Removal of the dominant terminal shoots of boronia plants is standard practice immediately after flower harvesting so as to stimulate the boronia plants to put up more new shoots for the next season.

The study was conducted at Copping using three year old boronia plants at the end of the *C. thysanura* summer generation (April 10, 1987). The study area was divided into plots each 3 m by 10 m containing 20 boronia plants with a 4 m guard row between each plot. The two most effective insecticides, mevinphos and monocrotophos, were included in the general schedules of (1) insecticide stem spray followed by removal of dominant terminal shoots (2) insecticide stem spray alone, no pruning of shoots (3) insecticide foliage spray with pruning and (4) insecticide foliage spray, no pruning. Control plants were not sprayed, and either pruned or not pruned. In pruning, the top 20 cm of the terminal shoots were removed immediately after the treatments were established. The insecticides used in this study were applied at 0.02% a.i.

Psyllid nymphs and eggs were assessed by randomly sampling 10 "closed" terminal shoots per replicate and the shoots examined under a binocular microscope. All living psyllid nymphs, eggs and psyllid mummies were recorded; parasitoids emerging from mummies were counted. Pretreatment counts were made as in 2.4.1, i.e., at 7-day intervals up to 56 days with the 28 day count a pretreatment count for a second insecticide application.

2.4.3 Optimum timing of insecticide sprays

Following the analysis of experiment 2.4.2, it was evident that pruning contributed little to control with mevinphos used as either a stem or foliage spray, whereas monocrotophos killed parasitoids within mummies when used as a foliage

spray.

This experiment, which should have been conducted earlier, was performed in the 1988/89 season. Although the optimum time to spray was known from the population studies (Chapter 5), this study was necessary to determine the effects of spraying on peak numbers of early and late stage psyllid nymphs and the parasitoids. Certain growers considered such sprays essential.

Two experiments were conducted separately using mevinphos stem spray in one experiment and monocrotophos foliage spray in the other. Both experiments were conducted on 4 year old boronia plants at Copping from November 1988 to April 1989. In each of the experiments, the chemical being tested (either mevinphos SS or monocrotophos FS) was applied at (1) the peak of the early nymphal stage (1-3 instars) when parasitoids were active and feeding within the psyllid nymph and (2) the peak of the late nymphal stage (4-5 instars) when the parasitoids had killed the host nymphs and were within the mummified nymphs. Both insecticides were sprayed at 0.02% a.i. with a knapsack sprayer.

Each treated plot was 3 m wide by 10 m long and consisted of 20 boronia plants. The design for each experiment was a randomised block with seven replicates. A 4 m guard row separated each replicate to reduce insecticide drift.

In the mevinphos SS plot, stems were sprayed ensuring that foliage was unsprayed. This was followed by the removal of dominant terminal shoots of the plants. In the monocrotophos FS plots, the whole plant was sprayed (both stems and foliage) and followed by pruning. Control plots in each of the two experiments were set up, with the terminal shoots of the plants removed and left unsprayed.

C. thysanura nymphs and eggs were assessed for each of the two experiments taking 10, 15 cm shoots per replicate as in section 2.4.1. Pretreatment counts were taken 24 h before spraying, 3 days post-treatment to assess nymphal mortality, and thereafter, counts made at 4 week intervals until April, 1989. Both studies received the initial application followed by a second treatment at 28 days.

2.4.4 Number of applications of chemicals required to effectively control *C. thysanura.*

The aim of this study was to determine the number of field applications of mevinphos stem spray required in a season that effectively reduced *C. thysanura* numbers while having no effect on parasitoid populations. In a second experiment, monocrotophos foliage spray was used to determine the number of applications required in a season to reduce *C. thysanura* in the absence of parasitoids. This second experiment was carried out because some boronia growers had changed from demeton-S-methyl to monocrotophos as a foliage spray.

These two experiments were conducted on 3 year old plants at Copping from December 17 1987 until August 25 1988. The study area for each experiment was divided into plots similar to those described in 2.4.1. and 2.4.2.

In each of the trials, the chemicals being tested (either mevinphos stem spray or monocrotophos foliage spray) were applied three times (23/12/1987, 20/1/1988 and 21/4/1988) at the end of the *C. thysanura* generations. The December and January applications were carried out 28 days apart. Plots of unsprayed plants provided controls for each experiment. Insecticides were diluted to 0.02% a.i. and applied with a knapsack sprayer at 420 ml toxicant/min.

The design for each experiment was a randomised block with seven replicates. The stems of the boronia plants were sprayed with mevinphos followed by the removal of the dominant terminal shoots. Monocrotophos was applied to both foliage and stems and then the plants were pruned.

Ten 15 cm long terminal shoots were randomly selected from each replicate plot and numbers of psyllid eggs, nymphs and mummified nymphs were recorded. Pretreatment counts were taken 24 h prior to spraying followed by a count three days after spraying to assess nymphal mortality. Subsequent counts were taken every four weeks for eight months.

The growth of the plants in each treated plot was assessed by recording the number of new nodes formed per terminal shoot during the study period as in 2.4.2.

2.4.5 The evaluation of mevinphos stem, and monocrotophos foliage sprays

The field trials were conducted on the basis of the performance of the two chemicals when applied to different sites on the infested plants. The aim was to determine whether these two chemicals could perform equally well in different areas in Tasmania. Mevinphos as stem spray was selected on the basis of its effectiveness in reducing *C. thysanura* numbers while conserving parasitoid populations. Monocrotophos as a foliage spray was selected on the basis of its higher toxicity to *C. thysanura* compared with other insecticides screened. The experiments were conducted on boronia farms at Copping, Huonville and Bakers Beach in 1987/88, 1988/89 and 1988/89, respectively. The design for the experiment was a randomised block with seven replicates. Each treated plot measured 3 m wide by 30 m long and consisted of 60 boronia plants. The stem and foliage sprays were applied as described in Sections 2.4.1 and 2.4.2. Control plots were left unsprayed. All plots were pruned 24 h after spraying.

Terminal shoots were collected 24h pretreatment to assess numbers of *C. thysanura* eggs, nymphs and mummified nymphs. A three day post-treatment count was taken in each plot followed by a count 28 days later, immediately before the second application in January in all the study sites. As before, this count served as a pretreatment count for the second spray. Thereafter, counts were taken at 4 week intervals until August at Copping, July at Huonville and March at Bakers Beach. The trial at Bakers Beach was concluded earlier than those at Huonville and Copping because the plants were heavily attacked and destroyed by the rust, *P. boroniae* ,so that further psyllid assessment was impractical.

The method of population assessments of psyllid eggs, nymphs and mummified nymphs at all sites was similar to that used in the small scale trial (Section 2.4.1) i.e., 10 shoots per replicate were dissected to expose the stages. Mummified psyllid nymphs collected from each treated plot were kept separately and the number of parasitoids that emerged, recorded.

2.4.5.1 Growth assessment

The growth of the plants in each treated plot at all sites was assessed by the

production of new nodes during the study period as described in Section 2.4.1.

2.4.5.2 Flower yield assessment

The number of flowers on each tagged terminal shoot for each treated and control plot was recorded during flower harvesting in September. The flowers of all 10 plants for each treated plot were harvested separately, weighed and recorded. To obtain oil yields, the flowers were solvent-extracted by a chemist from Essential Oils of Tasmania. A comparison was made of the flower and oil yields and economics of pest control for commercial boronia crops receiving monocrotophos as a foliage spray and the IPM mevinphos as a stem spray followed by pruning relative to the unsprayed control boronia plants at both Copping and Huonville. In addition, a comparison was made of the economics of control on one farm before and after the integrated control programme was implemented.

2.4.5.3 Chemical residue analysis of boronia oil

The boronia oil was analysed to establish whether any residue of either mevinphos or monocrotophos was present. The analysis was carried out in the laboratory of the Tasmanian State Government Analyst using the method of Zweig and Sherma (1972). The limits of detection for the two insecticides in the analysis were 0.2 ppm for mevinphos and 0.6 ppm for monocrotophos.

3. Results

3.1 Glasshouse tests

3.1.1 Selection of appropriate insecticide

The effects of different systemic insecticides tested at different concentrations are summarised in Table 59.

Table 59

Mortality of *C.thysanura* (5th nymphal stages) following treatment with different systemic insecticides at different concentrations. (mean of 10 replicates per treatment).

Insecticides	Dosage a.i v/v (%)	Per cent mortality (after 3 days)
Metasystox (25EC)	0.01	46.0a
Demeton-S-methyl	0.02	90.0b
	0.03	100.0c
	0.04	100.00c
Rogor (30EC)	0.01	46.0a
Dimethoate	0.02	92.0b
	0.03	100.0c
	0.04	100.0c
Nuvacron (40EC)	0.01	48.0a
Monocrotophos	0.02	94.0b
	0.03	100.0b
	0.04	100.0b
Phosdrin (36EC)	0.01	52.0a
Mevinphos	0.02	96.0b
	0.03	100.0b
	0.04	100.0b

Means within a column (for each insecticide treatment) followed by the same letter are not significantly different P>0.05,Duncan's multiple range test.

Metasystox{Lsd(0.05)=8.80;Lsd(0.01)=11.88}
Rogor{Lsd(0.05)=7.30;Lsd(0.01)=9.86
Nuvacron{Lsd(0.05)=6.39;Lsd(0.01)=8.63}
Phosdrin{Lsd(0.05) =6.02;Lsd(0.01)=8.12

All chemicals tested at 0.02, 0.03 and 0.04 per cent caused greater than 85 per cent kill three days after treatment, whereas 0.01 was significantly less. All the chemicals were therefore further tested in the field at a concentration of 0.02 per cent a.i. to determine the most efficient method of application.

3.2 Field trials

3.2.1 Determination of the most effective application method

Insecticides applied as foliage sprays (FS) caused the highest per cent kill of *C. thysanura* nymphs and lower nymphal survival rates ($P<0.01$) than stem sprays (SS) during the period of study (the exception was mevinphos stem spray) (Table 60). Among the foliage sprayed chemicals, demeton-S-methyl had the highest nymphal recovery rate (22.69), indicating the lower persistence of the chemical. Although insecticides applied as stem sprays were generally less effective than foliage sprays, they had a significantly lower ($P<0.01$) *C. thysanura* survival rate than that for unsprayed plots (Table 60). The growth of boronia plants following treatment is shown in Table 61. The boronia plants which received foliage sprays with either of the insecticides tested produced greater numbers of nodes per shoot ($P<0.01$) than did plants which received stem sprays ,with the exception of plants that received mevinphos as a stem spray (Table 61). Monocrotophos FS and dimethoate FS plants showed most growth (7.30 nodes/shoot) although this was not significantly different ($P>0.05$) from the other FS plants or plants on the mevinphos SS plots. The plants on the unsprayed plots had significantly less growth ($P<0.01$) (Table 61).

Table 60

Effect of site of spray application on *C.thysanura* nymphs on boronia plants sprayed on either foliage or stem with four systemic insecticides at Copping,1986-87. (Mean of 70 terminal shoots per treatment)

Insecticides/method of placement	Mean no.of nymphs/terminal shoot									Cumulative total (Survival rate)	Mean % mortality after 3 days
	24hrs Pre-treatment counts	Post treatment counts(days) 7	14	21	28	35	42	49	56		
Metasystox(Foliage spray)	7.29	0.94	4.69	5.10	6.01	0.62	1.40	1.67	2.26	22.69	93.6
(Demeton-S-methyl)(Stem spray)	5.60	3.26	5.36	6.74	7.59	4.29	5.56	5.94	6.54	45.28	51.3
Rogor (Foliage spray)	6.84	0.90	3.03	3.50	5.64	0.10	0.29	0.49	0.79	14.74	97.2
(Dimethoate) (Stem spray)	6.76	3.63	5.46	6.24	8.00	4.79	5.26	5.64	6.20	45.22	59.4
Nuvacron (Foliage spray)	7.54	0.81	2.50	2.97	3.82	0.04	0.06	0.10	0.14	10.44	97.6
(Monocrotophos)(Stem spray)	8.14	5.30	5.34	6.54	7.87	5.73	6.61	6.60	7.30	51.29	49.9
Phosdrin (Foliage spray)	6.91	0.67	3.87	4.42	5.04	0.09	0.21	0.27	0.31	14.88	97.9
(Mevinphos) (Stem spray)	7.34	1.31	4.91	5.01	5.66	0.61	1.02	1.26	2.07	21.85	90.0
Control (Unsprayed plot)	6.16	6.89	7.37	7.26	8.79	7.71	8.29	6.39	5.83	58.53	-11.0

Lsd(0.05)=4.98;Lsd(0.01)=6.62

Each of the insecticides was sprayed at 0.02% a.i v/v and spraying was repeated at 28 days interval. Per cent treatment mortalities were collected by means of Abbott(1925) formula.

Table 61

Effect of site of application of four systemic insecticides on the growth of boronia plants at Copping,1986-87. (Mean of 10 replicates per treatment).

Insecticides/method of placement		Mean no.of new nodes/terminal shoot
Demeton-S-methyl	(Foliage spray)	7.23a
	(Stem spray)	4.03b
Dimethoate	(Foliage spray)	7.30a
	(Stem spray)	4.46bc
Monocrotophos	(Foliage spray)	7.30a
	(Stem spray)	4.86c
Mevinphos	(Foliage spray)	7.22a
	(Stem spray)	7.10a
Control (Unsprayed plot)		2.64d

Lsd(0.05)=0.53;Lsd(0.01)=0.70

Means followed by the same letter are not significantly different P>0.05, Duncan's multiple range test.

3.2.1.1 Effect of site of applications on the survival of parasitoids of *C. thysanura*

The high per cent parasitoid emergence and survival rates from stem sprayed plots compared with foliage sprayed plots indicated that stem sprays had very little effect on parasitoid survival (Table 62). The survival rates of the parasitoids on the stem sprayed plots did not differ significantly (P>0.05) from that of the unsprayed

plots. No parasitoids emerged from mummified nymphs collected from foliage sprayed plots with the exception of demeton-S-methyl foliage sprayed plots which had 16.4 per cent parasitoid emergence (Table 62). Mevinphos SS and monocrotophos FS were the promising chemicals and were selected for further trials to incorporate pruning of shoots.

3.2.2 Evaluation of chemical sprays followed by the pruning of terminal shoots of boronia plants on *C. thysanura* populations.

Results of the effect of chemical sprays followed by pruning of dominant terminal shoots of boronia plants on *C. thysanura* eggs and nymphs are given in Tables 63 and 64. There was no significant difference ($P>0.05$) in the survival of *C. thysanura* eggs and nymphs with chemical sprays on either pruned or unpruned plants. In the control plots, plants that were pruned had significantly lower ($P<0.01$) survival of *C. thysanura* eggs (27.70) and nymphs (27.48) than plots where plants were left unpruned (survival rates of 37.60 for eggs and 55.89 for nymphs) (Table 63). Pruning of terminal shoots had 31.6 per cent nymphal mortality after 7 days, but there was a 13.6 per cent increase of *C. thysanura* nymphs in plots left unpruned (Table 63). Pruning, therefore, had some control of *C. thysanura* eggs and nymphs.

The effect of chemical sprays followed by pruning on the parasitoids attacking *C. thysanura* is shown in Table 65. Mevinphos SS followed by pruning had no effect on per cent parasitoid emergence from mummified nymphs. No parasitoids emerged from mummified psyllid nymphs collected from plots which received either monocrotophos FS or mevinphos FS on pruned or unpruned plants, indicating that foliage sprays killed the parasitoids.

In the control, the pruned plots had 95 per cent parasitoid emergence from mummified nymphs compared with 96.2 per cent on the unpruned plants,indicating that pruning had no effect on the survival of parasitoids. Mevinphos SS and monocrotophos FS followed by pruning were further tested to determine the optimum

Table 62

Effect of site of spray application of different systemic insecticides on the survival of parasitoids of *C.thysanura* when boronia plants were sprayed on either foliage or stem. (Mean of 70 terminal shoots per treatment).

Insecticides/method of placement	Mean no.of mummified psyllid nymphs/terminal shoot									Cumulative total (Survival rate)	Mean parasitoid emergence (per cent)
	24hrs Pre-treatment counts	Post treatment counts (days)									
		7	14	21	28	35	42	49	56		
Demeton-S-methyl(Foliage spray)	0.13	0.11	0.07	0.04	0.06	0.04	0.09	0.01	0.04	0.46	16.4
(Stem spray)	0.10	0.09	0.10	0.06	0.16	0.10	0.21	0.26	0.21	1.19	89.0
Dimethoate (Foliage spray)	0.10	0.13	0.06	0.01	0.07	0.00	0.01	0.03	0.03	0.34	0.0
(Stem spray)	0.07	0.11	0.10	0.06	0.06	0.19	0.17	0.24	0.29	1.22	86.3
Monocrotophos (Foliage spray)	0.13	0.13	0.04	0.01	0.01	0.01	0.01	0.00	0.01	0.22	0.0
(Stem spray)	0.14	0.11	0.20	0.03	0.19	0.19	0.19	0.15	0.17	1.23	85.5
Mevinphos (Foliage spray)	0.13	0.16	0.09	0.01	0.00	0.03	0.00	0.03	0.01	0.33	0.0
(Stem spray)	0.10	0.13	0.11	0.04	0.17	0.16	0.25	0.14	0.24	1.24	90.4
Control (Unsprayed plot)	0.10	0.11	0.09	0.04	0.14	0.16	0.27	0.21	0.24	1.26	91.7

Lsd(0.05)=0.12;Lsd(0.01)=0.16 (Between insecticide treatments)

All insecticides were applied at 0.02% a.i v/v and spraying was repeated at 28 days interval.

Table 63

Effect of chemical spraying followed by removal of dominant terminal shoots of boronia plants (pruning) on *C.thysanura* eggs at Copping,1987.

Treatments	Mean no.of eggs/terminal shoot						Cumulative total (Survival rate)
	24hrs Pre-treatment counts	Post treatment counts(days) 7	14	28	35	56	
Pruning only	12.96	7.64	1.84	1.90	1.69	14.63	27.70
Mevinphos(SS)+Pruning	9.99	5.54	0.84	0.87	0.83	2.20	10.28
Mevinphos(SS)+No pruning	9.10	3.90	1.36	0.12	0.16	8.20	13.74
Mevinphos(FS)+Pruning	4.01	3.44	0.70	0.09	0.04	2.76	7.03
Mevinphos(FS)+No Pruning	8.83	5.43	1.26	0.07	0.06	2.91	9.73
Monocrotophos(FS)+Pruning	9.53	5.29	0.60	0.59	0.10	0.61	7.19
Monocrotophos(FS)+No Pruning	9.87	4.84	1.21	0.21	0.16	1.04	7.46
Control(Not sprayed,Not pruned)	4.90	4.31	3.56	6.96	9.36	13.41	37.60

Lsd(0.05)=4.73; Lsd(0.01)=6.32

Table 64

Effect of chemical spray followed by pruning of boronia plants on *C.thysanura* nymphs at Copping,1987.

Treatments	Mean no.of nymphs/terminal shoot						Cumulative total (Survival rate)	Mean mortality after 7 days (Per cent)
	24hrs Pre-treatment counts	Post treatment counts (days) 7	14	28	35	56		
Pruning only	10.74	4.86	5.84	5.99	5.49	5.30	27.48	31.6
Mevinphos(SS)+Pruning	15.87	1.44	2.83	4.66	0.97	1.76	11.66	85.1
Mevinphos(SS)+No Pruning	10.73	1.67	4.04	6.61	1.27	3.36	16.95	82.6
Mevinphos(FS)+Pruning	5.79	1.09	2.84	4.37	0	0.51	8.81	90.6
Mevinphos(FS)+No Pruning	10.90	1.57	3.40	5.39	0.44	0.33	11.13	88.7
Monocrotophos(FS)+Pruning	9.17	0.70	1.17	2.77	0.21	0.09	4.94	92.3
Monocrotophos(FS)+No Pruning	10.11	0.69	1.90	3.14	0.35	0.71	6.79	91.0
Control(Not sprayed,Not pruned	10.79	10.36	10.56	10.34	13.77	10.86	55.89	-13.6

Lsd(0.05)=5.63; Lsd(0.01)=7.53

SS+Pruning=Stem spray followed by pruning; FS+Pruning=Foliage spray followed by pruning.

time of spray application that conserved the parasitoids while controlling the psyllids.

Table 65

Effect of chemical spraying followed by pruning of boronia plants on *C.thysanura* parasitoid population at Copping,1987.

Treatments	No.of mumified psyllid nymphs collected 7 days after treatment	Mean parasitoid emergence (Per cent)
Pruning only	20	95.0
Mevinphos(SS)+Pruning	18	94.4
Mevinphos(SS)+No Pruning	15	93.3
Mevinphos(FS)+ Pruning	17	0
Mevinphos(FS)+No Pruning	22	0
Monocrotophos(FS)+Pruning	19	5.3
Monocrotophos(FS)+No Pruning	26	3.9
Control(Not sprayed,No pruning)	26	96.2

3.2.3 Optimum timing of insecticide spray

3.2.3.1 Effect of treatment applications on *C. thysanura* eggs and nymphs

The effects of timing of insecticide sprays on *C. thysanura* eggs and nymphs are shown in Tables 66, 67, 68 and 69.

C. thysanura egg survival was significantly lower ($P<0.01$) when either monocrotophos FS or mevinphos SS was applied at the peak of the late nymphal stage compared with application at the early nymphal stage, indicating greater suppression of psyllid egg numbers when chemicals were applied at the peak of the late nymphal stage (Tables 66 and 67).

Table 66

Effect of timing of monocrotophos foliage spray on *C.thysanura* eggs at Copping,1988-89. (Mean of 70 terminal shoots per treatment).

Time of spray treatment application	Mean no.of eggs/terminal shoot 24hrs Pre-treatment counts	Post treatment counts(months) Dec.	Jan.	Feb.	Mar.	April	Cumulative total (Survival rate)
1.At peak of early nymphal stage population	9.13a	0.30a	1.24a	5.41ab	7.20ab	7.73a	21.88
2.At peak of late nymphal stage population	9.87a	1.66a	0.14a	0.86b	3.47b	2.59b	8.72
3. Control (Not sprayed)	5.90a	6.96b	9.36b	8.97a	8.71a	9.44a	43.44

Lsd(0.05)=4.65; Lsd(0.01)=6.51

Table 67

Effect of timing of mevinphos stem spray applications on *C.thysanura* eggs at Copping, 1988-89.(Mean of 70 terminal shoots per treatment).

Time of spray treatment application	Mean no.of eggs/terminal shoot 24hrs Pre-treatment counts	Post treatment counts (months) Dec.	Jan.	Feb.	Mar.	April	Cumulative total (Survival rate)
1. At peak of early nymphal stage population	9.99a	0.87a	7.20a	9.30a	10.73a	7.79a	35.89
2. At peak of late nymphal stage population.	9.10a	3.83a	0.74b	4.80b	7.47a	6.17a	23.01
3. Control (Not sprayed)	5.96a	4.30a	5.86a	9.51a	8.40a	10.03a	38.10

Lsd(0.05)=4.12; Lsd(0.01)=5.78

Means within columns followed by the same letter are not significantly different,P>0.05, Duncan's multiple range test.

Table 68

Effect of timing of mevinphos stem spray applications on *C.thysanura* nymphs at Copping,1988-89. (Mean of 70 terminal shoots per treatment).

Time of spray treatment application	Mean no.of nymphs/terminal shoot						Cumulative total (Survival rate)	Mean mortality after 3 days (Per cent)
	24hrs Pre-treatment counts	Post treatment counts (months)						
		Dec.	Jan.	Feb.	Mar.	April		
1. At peak of early nymphal stage population	16.13a	4.66a	1.86a	9.70a	13.91a	13.20a	43.33	90.50
2. At peak of late nymphal stage population	9.30b	9.99a	1.57a	1.70b	6.99b	6.46b	26.71	92.50
3. Control (Not sprayed)	10.06b	5.19a	4.23a	14.49a	17.06a	14.64a	55.61	-47.02

Lsd(0.05)=5.71; Lsd(0.01)=8.00

Table 69

Effect of timing of monocrotophos foliage spray application on *C.thysanura* nymphs at Copping, 1988-89.(Mean results of 70 terminal shoots per treatment).

Time of spray treatment application	Mean no.of nymphs/terminal shoot						Cumulative total (Survival rate)	Mean mortality after 3 days (Per cent)
	24hrs Pre-treatment counts	Post treatment counts (months)						
		Dec.	Jan.	Feb.	Mar.	April		
1.At peak of early nymphal stage population	9.40a	2.91a	0.09a	3.54a	8.84a	11.17a	26.55	96.60
2. At peak of late nymphal stage population	7.26a	7.54a	0.83a	0.27a	3.49a	3.46b	15.59	97.70
Control (Not sprayed)	10.34a	10.79a	9.27b	13.87b	19.14b	10.29a	63.36	10.15

Lsd(0.05)=6.04; Lsd(0.01)=8.47

Means within columns followed by the same letter are not significantly different,P>0.05, Duncan's multiple range test.

Percent mortalities were corrected by means of Abbott(1925) formula.

Irrespective of time of application, both monocrotophos FS and mevinphos SS caused high nymphal mortality (over 90 per cent) three days after treatment (Tables 68 and 69). However, in both monocrotophos FS and mevinphos SS plots, *C. thysanura* nymphal survival was significantly lower ($P<0.01$) when insecticide was applied at the peak of the late nymphal stage compared with the early nymphal stage, suggesting a high degree of control of nymphs when the chemical was applied at the peak of the late nymphal stage. Although a high degree of control of *C. thysanura* nymphs was not achieved when either insecticide was applied at the peak of the early nymphal stage, the extent to which nymphs were controlled was significantly better ($P<0.01$) than in the unsprayed control plots (Tables 68 and 69).

3.2.3.2 Effect of treatment applications on the growth of the boronia plants

The effects of timing of insecticide spray application against *C. thysanura* on the growth of boronia plants are given in Tables 70 and 71.

The numbers of new nodes produced by boronia plants at the end of the study were significantly higher ($P<0.05$) when either chemical spray was applied at the peak of the late nymphal stages than during early nymphal stages. However, boronia plants which received chemical sprays at the peak of the early nymphal stage had significantly higher ($P<0.05$) growth than the unsprayed plants.

3.2.3.3 Effect of treatment applications on the parasitoid population

Tables 72 and 73 summarise the effects of the timing of insecticide spray on *C. thysanura* parasitoid populations. In insecticide-treated plots, parasitoid survival rates were significantly higher ($P<0.05$ for monocrotophos FS and $P<0.01$ for mevinphos SS) when sprays were applied at the peak of the late nymphal stage than at the early nymphal stage.

Parasitoid survival in the monocrotophos FS plots was significantly lower ($P<0.01$) irrespective of the time of application compared with the unsprayed plots, indicating that monocrotophos used as a foliage spray killed the parasitoid and its host (Table 72).

The parasitoid survival rate in the mevinphos SS plots applied at the peak of the

Table 70

Effect of timing of monocrotophos foliage spray applications on the production of new nodes on boronia plants at Copping,1988-89.(Mean of 10 replicates per treatment).

Time of spray treatment application	Mean no.of new nodes/terminal shoot 24hrs Pre-treatment counts	Post treatment counts (months) Dec.	Jan.	Feb.	Mar.	April
1.At peak of early nymphal stage population	0	5.40a	8.10a	8.60ab	9.80a	10.70a
2.At peak of late nymphal stage population	0	4.50a	8.00a	10.60b	13.00b	13.80b
3.Control (Not sprayed)	0	3.90a	5.80a	6.20a	6.90c	8.20c

Lsd(0.05)=2.43; Lsd(0.01)=3.32

Table 71

Effect of timing of mevinphos stem spray on the production of new nodes on boronia plants at Copping,1988-89.(Mean of 10 replicates per treatment).

Time of spray treatment application	Mean no.of new nodes/terminal shoot 24hrs Pre-treatment counts	Post treatment counts (months) Dec.	Jan.	Feb.	Mar.	April
1.At peak of early nymphal stage population	0	5.30a	6.80a	7.80a	9.30a	10.50a
2.At peak of late nymphal stage population	0	4.40a	7.60ab	10.10b	12.50b	13.40b
3.Control (Not sprayed)	0	3.90a	5.60a	6.70a	7.40a	8.00c

Lsd(0.05)=2.49; Lsd(0.01)= 3.40

Means within columns followed by the same letter are not significantly different,P>0.05,Duncan's multiple range test.

Table 72

Effect of timing of monocrotophos foliage spray applications on *C.thysanura* parasitoid population at Copping,1988-89.(Mean of 70 terminal shoots per treatment).

Time of spray treatment application	Mean no.of parasitiods/terminal shoot 24hrs Pre-treatment counts	Post treatment counts (months) Dec.	Jan.	Feb.	Mar.	April	Cumulative total (Survival rate)
1.At peak of early nymphal stage population	0	0a	0a	0a	0.03a	0.06a	0.09
2.At peak of late nymphal stage population	0	0.17b	0.01a	0a	0a	0.01a	0.19
3.Control (Not sprayed)	0	0.23b	0.23b	0.06a	0.06a	0.33b	0.91

Lsd(0.05)=0.13; Lsd(0.01)=0.18

Table 73

Effect of timing of mevinphos stem spray applications on *C.thysanura* parasitoid populations at Copping,1988-89.

Time of spray treatment application	Mean no.of parasitoid/terminal shoot 24hrs Pre-treatment counts	Post treatment counts (months) Dec.	Jan.	Feb.	Mar.	April	Cumulative total (Survival rate)
1.At peak of early nymphal stage population	0	0.01a	0a	0a	0.07a	0.10a	0.18
2.At peak of late nymphal stage population	0	0.23b	0.17b	0.03a	0.06a	0.36b	0.85
3. Control (Not sprayed)	0	0.30b	0.11b	0.03a	0.09a	0.39b	0.92

Lsd(0.05)=0.12; Lsd(0.01)=0.16

Means within columns followed by the same letter are not significantly different, P>0.05), Duncan's multiple range test.

late nymphal stage was 0.85 and this did not differ significantly (P>0.05) from that in the unsprayed plots (0.92) (Table 73). However, mevinphos SS applied at the peak of the early nymphal stage had a lower parasitoid survival rate of 0.18, indicating that incorrect timing of mevinphos SS killed the parasitoids. Mevinphos SS and monocrotophos FS followed by pruning applied at the peak of the late nymphal stage of *C. thysanura* were further tested to determine the number of applications in a season required to control the psyllid.

3.2.4 Number of applications of chemicals required to effectively control *C. thysanura*

The number of *C. thysanura* eggs and nymphs per terminal shoot during the period December 1987 to August 1988 on boronia plants which received different numbers of applications of mevinphos SS and monocrotophos FS are shown in Figs 58 and 59. The survival rates of eggs and nymphs are shown in Tables 74 and 75.

Table 74

Effect of number of field applications of monocrotophos foliage sprays on nymphal mortality, survival rates of *C.thysanura* eggs and nymphs and the growth of boronia plants at Copping,1987-88.

No.of spray applications	Mean nymphal mortality after 3 days (Per cent)	Cumulative total (Survival rate) of eggs	Cumulative total (Survival rate) of nymphs	Mean no.of nodes per terminal shoot at the end of study
2 sprays	96.40	86.31	73.02	11.00a
3 sprays	96.10	25.62	24.44	17.50b
No spray	-38.20	102.05	122.88	10.00a

No.of new nodes: Lsd(0.05)=6.43; Lsd(0.01)=8.80

Means within columns followed by the same letter are not significantly different, P>0.05, Duncan's multiple range test.

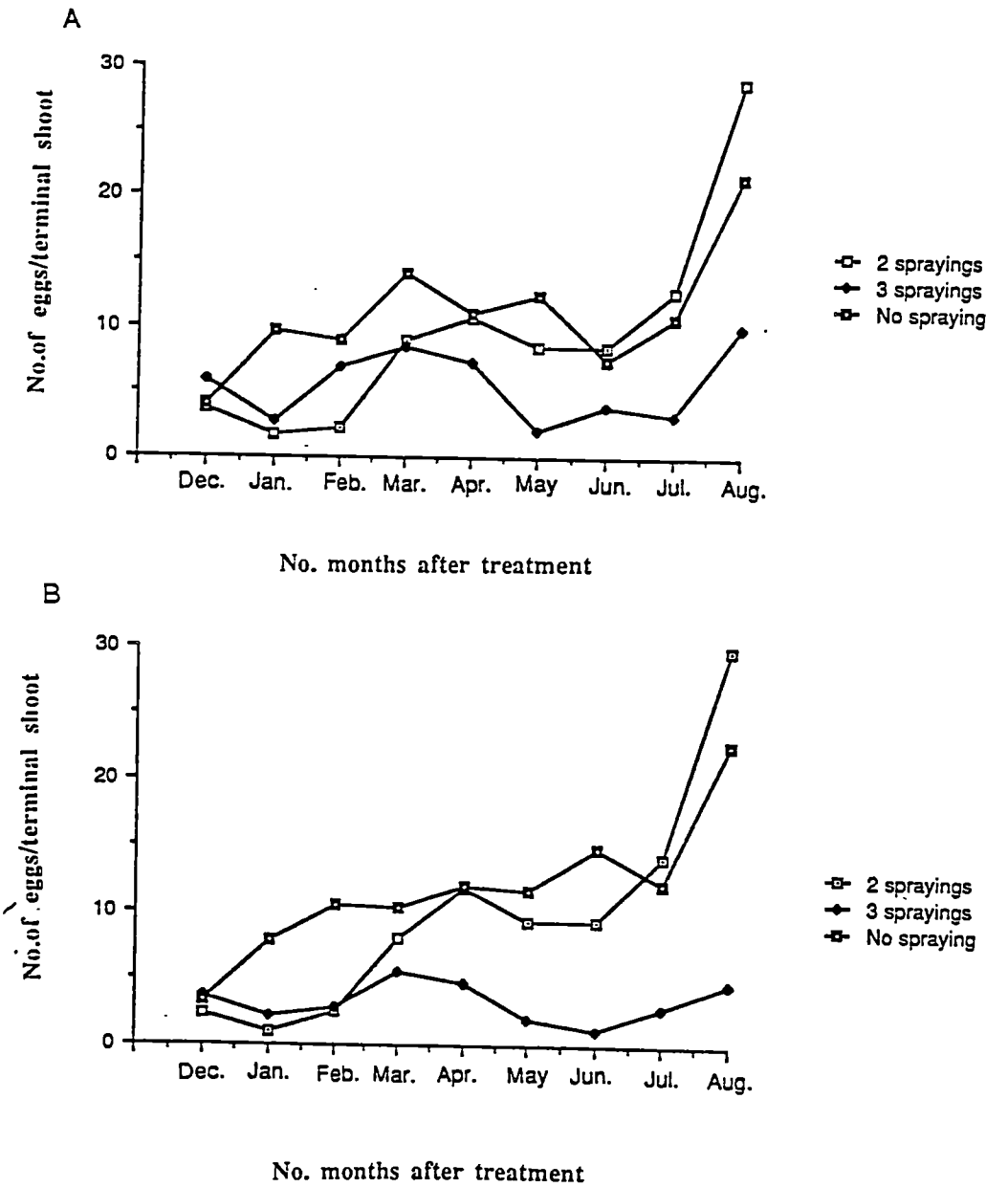


Fig. 58

Effect of different numbers of applications of (A) mevinphos as a stem spray and (B) monocrotophos as a foliage spray on *C.thysanura* eggs on boronia plants at Copping,1987-88. (Mean results of 70 terminal shoots per treatment).

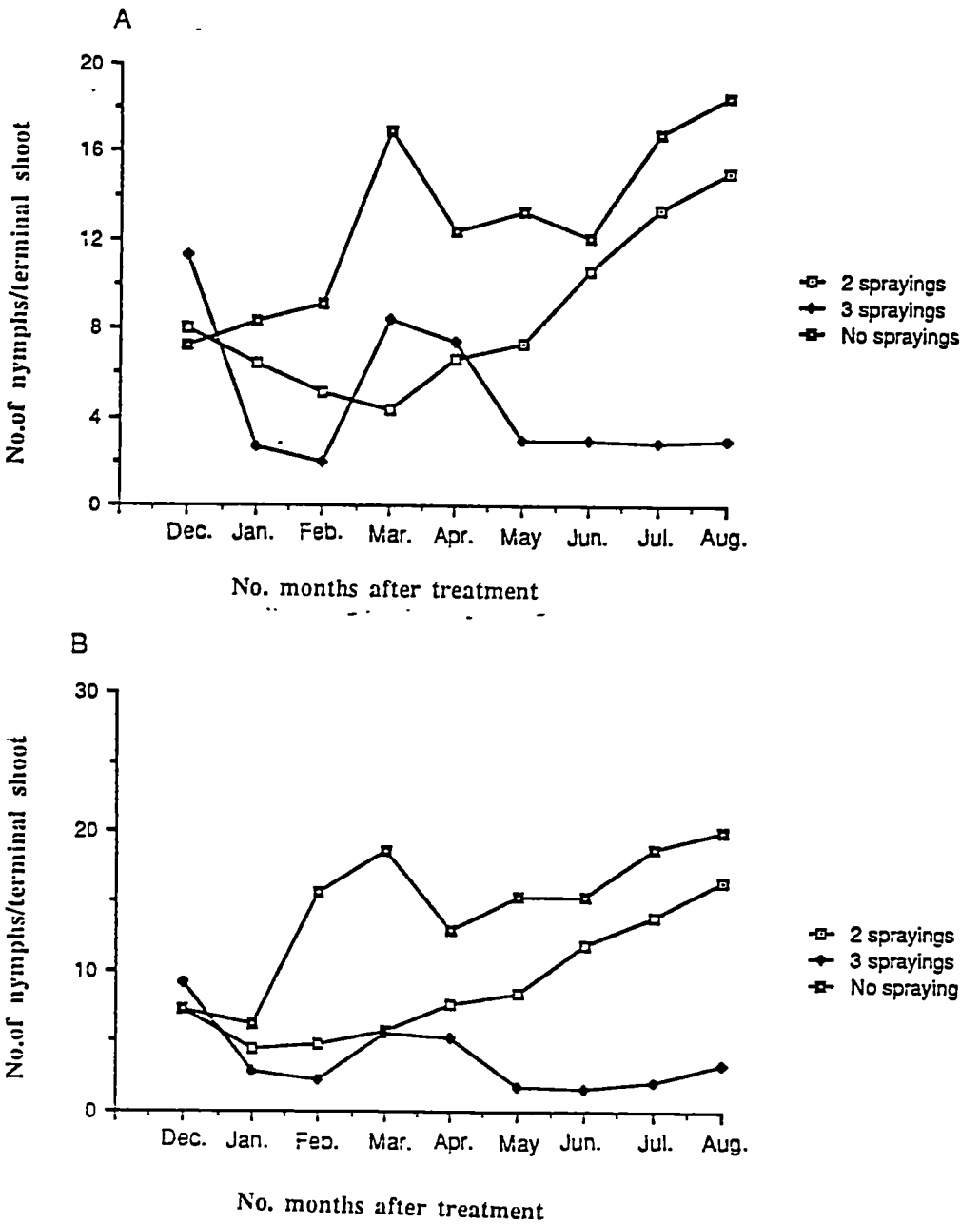


Fig. 59

Effect of different numbers of applications of (A) mevinphos as a stem spray and (B) monocrotophos as a foliage spray on *C.thysanura* nymphs on boronia plants at Copping.1987-88. (Mean results of 70 terminal shoots per treatment).

Mevinphos SS and monocrotophos FS plots which received three applications of either chemical had significantly lower ($P<0.01$) numbers of *C. thysanura* eggs and nymphs, or a lower survival rate, than the same plots that received two sprays and no spray application, respectively.

Table 75

Effect of number of field applications of mevinphos stem sprays on nymphal mortality,survival rates of eggs and nymphs and the growth of boronia plants at Copping, 1987-88.

No.of spray applications	Mean nymphal mortality after 3 days (Per cent)	Cumulative total (Survival rate) of eggs	Cumulative total (Survival rate) of nymphs	Mean no.of nodes per terminal shoot at the end of study
2 sprays	91.60	81.58	68.80	11.20a
3 sprays	90.80	44.22	32.35	16.20b
No spray	-45.80	95.12	107.35	9.30a

No.of new nodes Lsd(0.05)=4.80; Lsd(0.01)=6.58

Means within column followed by the same letter are not significantly different P>0.05,Duncan's multiple range test.

3.2.4.1 Effect of number of applications of chemicals on *C. thysanura* parasitoids

The number of parasitoids per terminal shoot in plots which received different spray applications of either mevinphos SS or monocrotophos FS are shown in Fig. 60. Parasitoid survival rates in these plots are shown in Tables 76 and 77.

There was no significant difference ($P>0.05$) in the number of parasitoids per shoot or the survival rate of parasitoids in mevinphos SS plots which received two or three spray applications and the unsprayed plots. In the monocrotophos FS plots, the

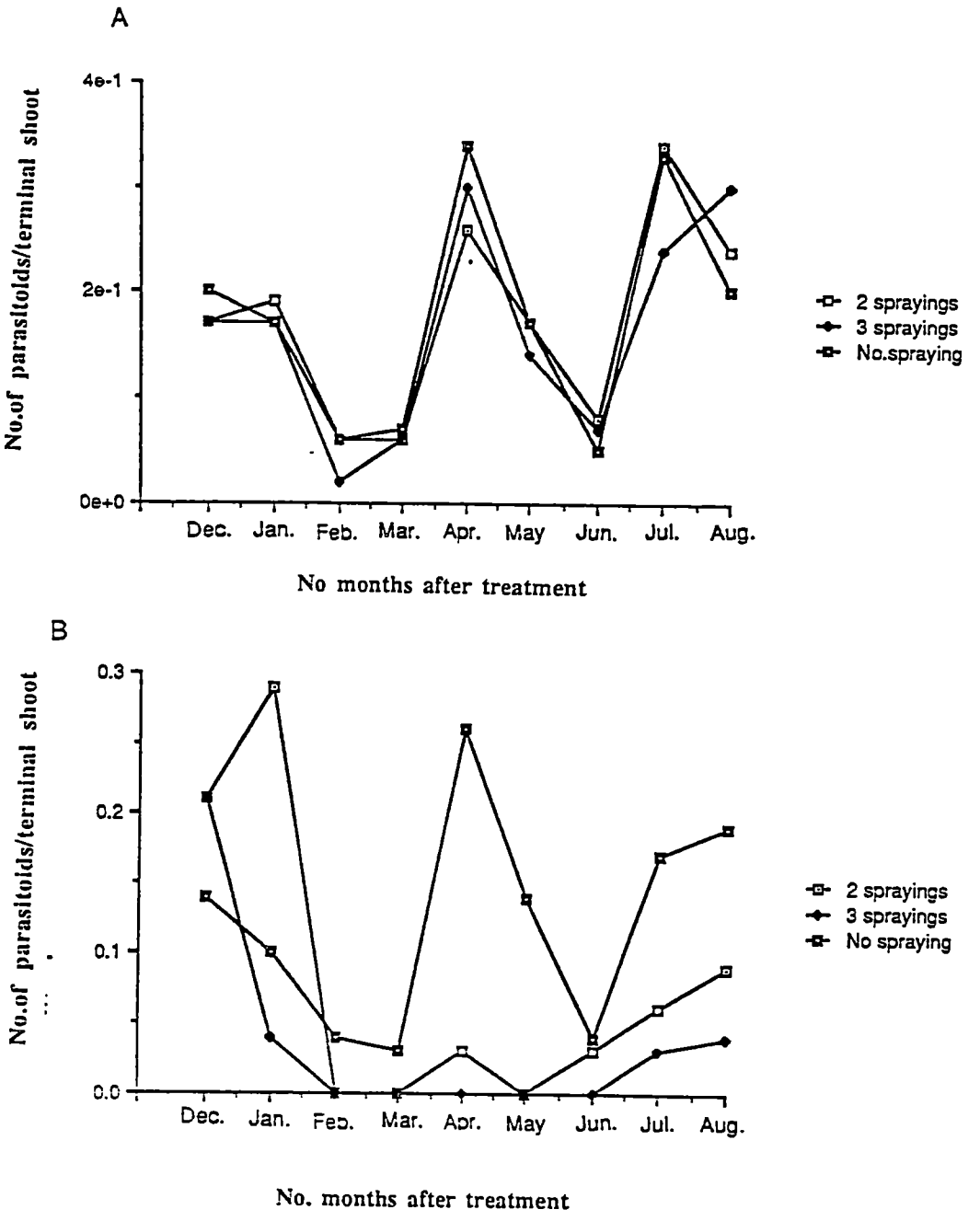


Fig. 60

Effect of different numbers of applications of(A) mevinphos stem spray and (B) monocrotophos foliage spray on *C.thysanura* parasitoid population on boronia plants at Copping.1987-88. (Mean results of 70 terminal shoots per treatment).

Table 76

Effect of number of field applications of mevinphos stem sprays on the survival of *C.thysanura* parasitiod populations at Copping,1987-88.

Number of treatment applications	Cumulative total (Survival rate)
2 sprays	1.40a
3 sprays	1.30a
No spray (Control)	1.39a

Lsd(0.05)=0.11; Lsd(0.01)=0.15

Table 77

Effect of number of field applications of monocrotophos foliage sprays on the survival of *C.thysanura* parasitoid populations at Copping,1987-88

Number of treatment applications	Cumulative total (Survival rate)
2 sprays	0.50a
3 sprays	0.11b
No spray (Control)	0.97c

Lsd(0.05)=0.11; Lsd(0.01)=0.16

Means followed by the same letter are not significantly different, P>0.05,Duncan's multiple range test.

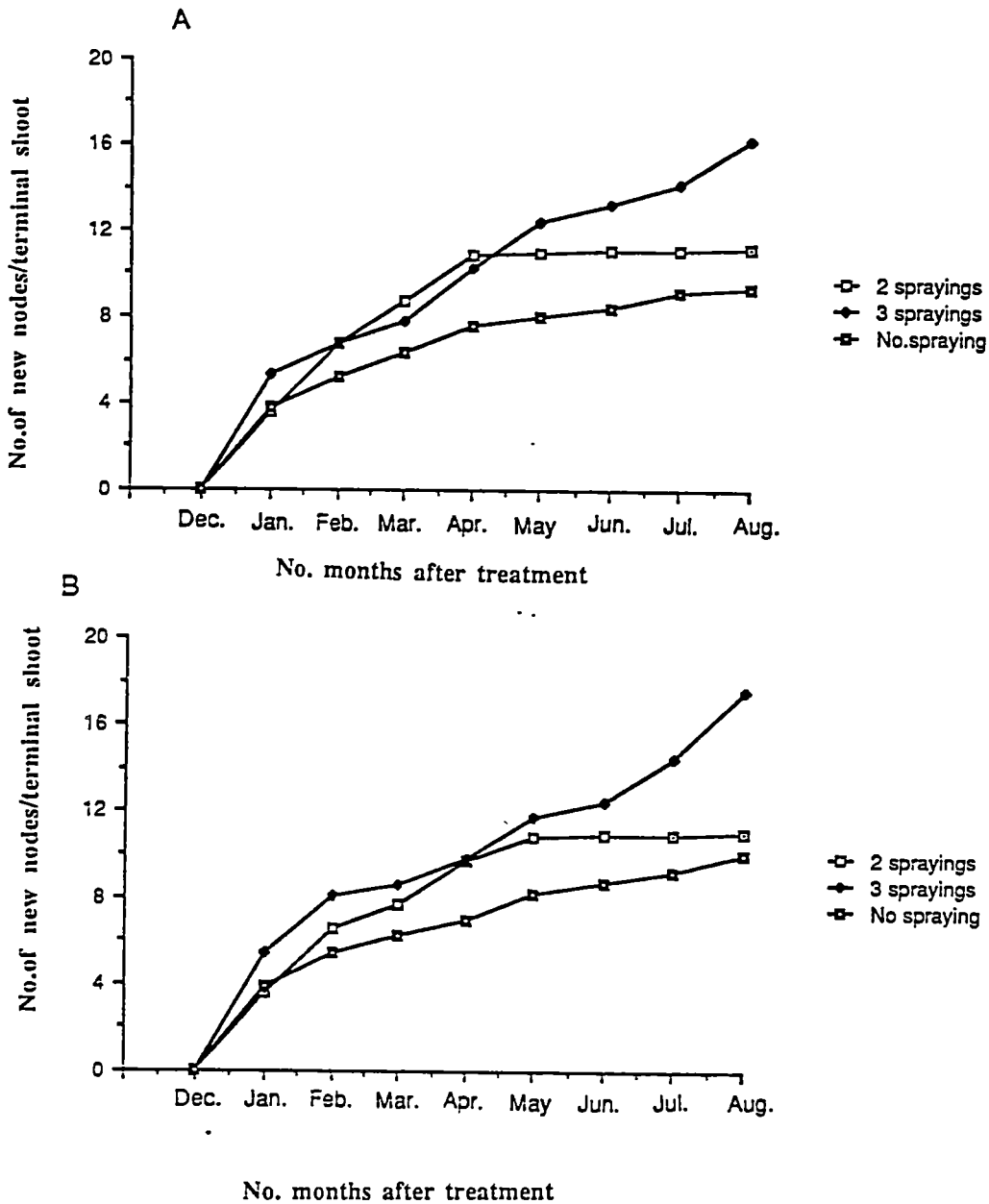


Fig. 61

Effect of different number of applications of (A) mevinphos as a stem spray and (B) monocrotophos as a foliage spray on the growth (new nodes per terminal shoot) of boronia plants at Copping,1987-88. (Mean results of 10 replicate per treatment).

number of parasitoids per shoot was significantly lower ($P<0.01$) than in the unsprayed plot, irrespective of the number of spray applications (Fig. 60B).

3.2.4.2 Effect of treatment application on the growth of boronia plants

The effect of the number of applications of either mevinphos SS or monocrotophos FS on the growth of boronia plants, expressed as the number of new nodes formed per shoot, is given in Fig. 61.

Plots which received three spray applications of either chemical produced more growth than plots which received either two or no spray applications, respectively. At the end of the study, monocrotophos FS sprayed plots which received three applications produced 17.50 nodes per terminal shoot, which was significantly higher ($P<0.05$) than plants which received two spray applications of the same chemical (11.00 nodes per shoot) or unsprayed plants (10.00 nodes per shoot) (Table 74). The mevinphos SS plots which received three sprays produced 16.20 nodes per shoot, which was significantly different from those which received two sprays (11.20 nodes per shoot) and the unsprayed plants (9.30 nodes per shoot) (Table 75).

3.2.5 The evaluation of mevinphos stem spray and monocrotophos foliage spray at different geographical sites

3.2.5.1 Effect of treatment applications on *C. thysanura* eggs and nymphs

The performance of mevinphos SS and monocrotophos FS in controlling *C. thysanura* eggs and nymphs at Copping, Huonville and Bakers Beach are shown in Figs. 62 and 63. The numbers of *C. thysanura* eggs and nymphs per terminal shoot in mevinphos SS and monocrotophos FS plots were significantly lower ($P<0.01$) than in the control plots at all study areas. Tables 78, 79 and 80 give a summary of *C. thysanura* egg and nymphal survival rates and nymphal mortality.

Table 78

Cumulative seaonal totals of *C.thysanura* eggs, nymphs and the mean percent nymphal mortality after application of either mevinphos stem spray or monocrotophos foliage spray at Copping,1987-88.

Insecticide/method of placement	Cumulative total (Survival rate) for eggs	Cumulative total (Survival rate) for nymphs	Mean nymphal mortality 3 days after spraying (Per cent)
Mevinphos stem spray)	36.20	23.41	91.60
Monocrotophos foliage spray)	23.85	15.49	94.60
Control (Not sprayed)	129.58	126.19	-34.00

Table 79

Cumulative seasonal totals of *C.thysanura* eggs,nymphs and the mean per cent nymphal mortality following application of either mevinphos stem spray or monocrotophos foliage spray at Huonville, 1988-89.

Insecticide/method of placement	Cumulative total (Survival rate) for eggs	Cumulative total (Survival rate) for nymphs	Mean nymphal mortality 3 days after spraying (Per cent)
Mevinphos stem spray	91.48	39.46	91.28
Monocrotophos foliage spray	70.39	33.38	96.18
Control(Not sprayed)	200.67	187.46	-45.19

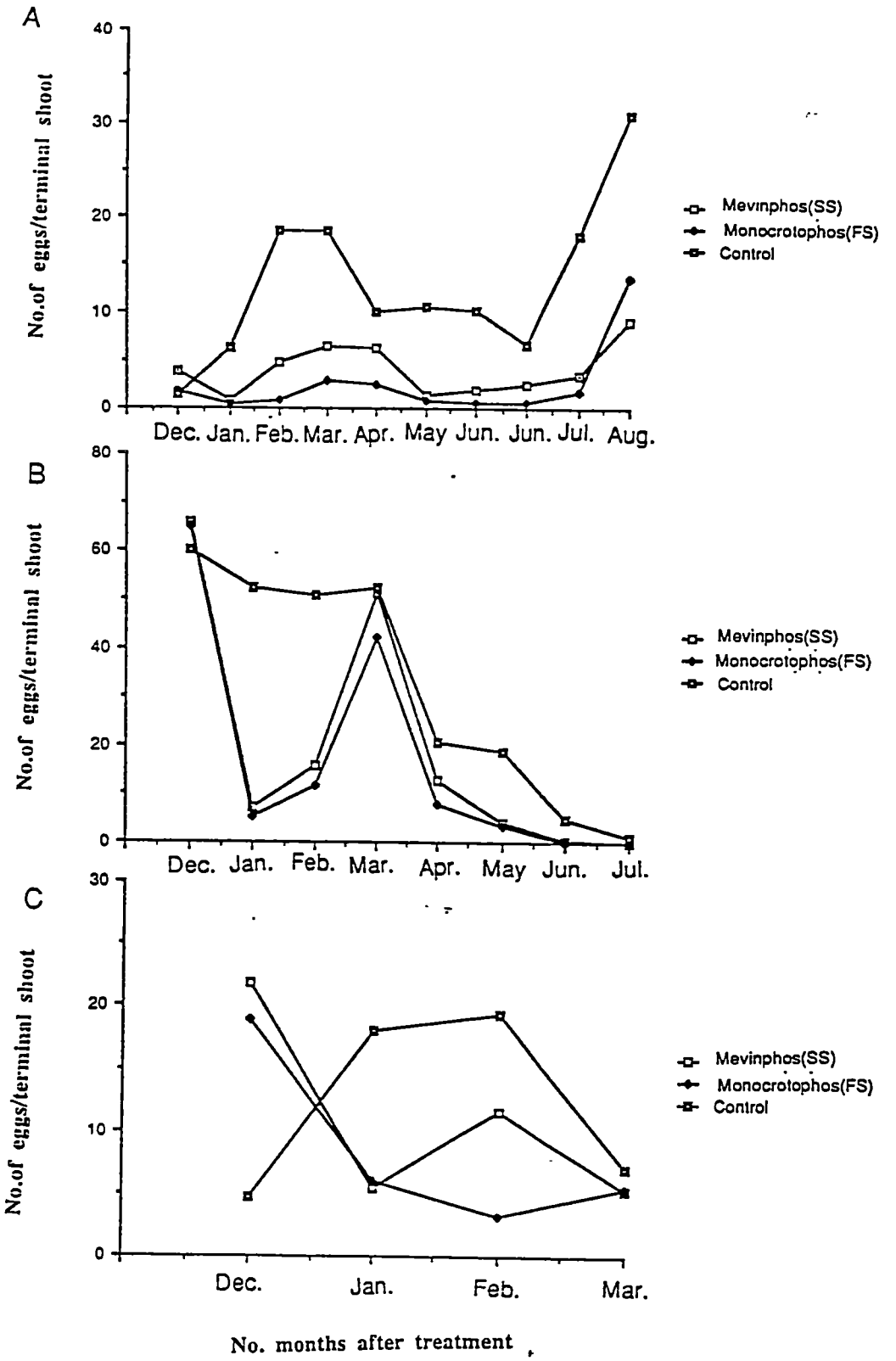


Fig. 62

Effect of mevinphos applied as a stem spray(mevinphos SS) and monocrotophos as a foliage spray(monocrotophos FS) on *C.thysanura* eggs on boronia plants at (A) Copping,(E.Tasmania,1987-88),(B) Huonville,(S.Tasmania,1988-89),and (C) Bakers Beach, (N.W.Tasmania, 1988-89). (Mean results of 70 terminal shoots per treatment).

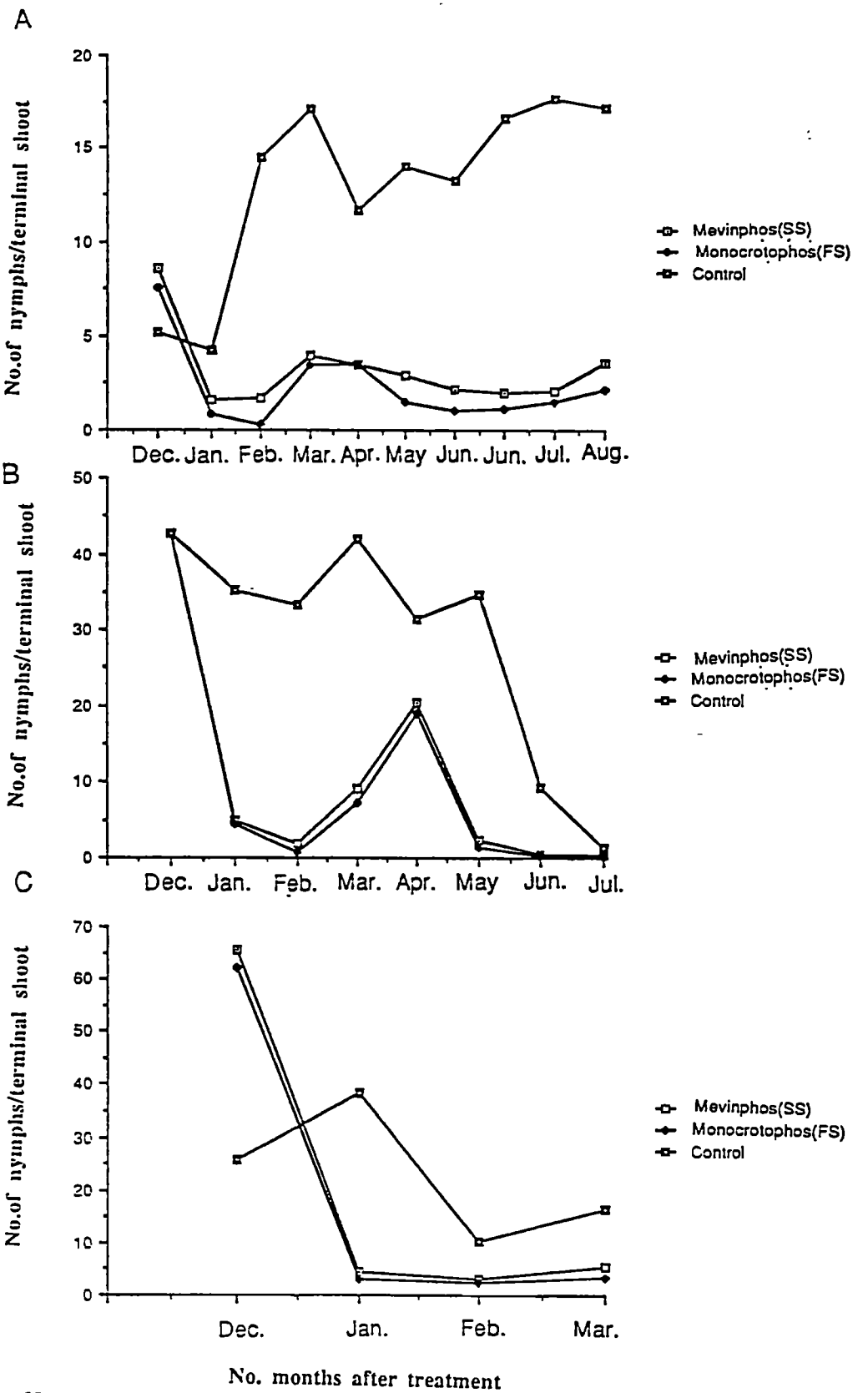


Fig. 63

Effect of mevinphos stem spray(mevinphos SS) and monocrotophos foliage spray(monocrotophos FS) on *C.thysanura* nymphs on boronia plants in a large scale trial at (A) Copping,1987-88, (B) Huonville,1988-89, and (C) Bakers Beach,1988-89. (Mean results of 70 terminal shoots per treatment).

Table 80

Cumulative seasonal totals of *C.thysanura* eggs,nymphs and the mean per cent nymphal mortality after application of either mevinphos stem spray or monocrotophos foliage spray at Bakers Beach,N.W.Tasmania,1988-89.

Insecticide/method of application	Cumulative total (Survival rate) of eggs	Cumulative total (Survival rate) of nymphs	Mean nymphal mortality after 3 days of spraying. (Per cent)
Mevinphos stem spray	22.31	12.93	93.00
Monocrotophos foliage spray	14.67	9.03	97.25
Control (Not sprayed)	44.44	40.20	19.29

Per cent mortalities were corrected by means of Abbott's (1925) formula.

C. thysanura egg and nymphal survival rates were significantly lower ($P<0.01$) on all the treated plots at all the study areas compared with the unsprayed plots. Both chemicals caused high nymphal kill (greater than 90 per cent) three days after spraying compared with control plots where nymphs increased by 34.90 per cent at Copping (Table 78) and 45.19 per cent at Huonville (Table 79).

3.2.5.2 Effect of treatment applications on the survival of *C. thysanura* parasitoid populations

The effects of monocrotophos foliage spray and mevinphos stem spray on the survival of the parasitoids of *C. thysanura* at Copping, Huonville and Bakers Beach are given in Fig. 64. The number of parasitoids per terminal shoot recorded in the monocrotophos FS plots was significantly lower ($P<0.01$) at all study areas than in mevinphos SS plots, the latter not differing significantly ($P>0.05$) from that in the

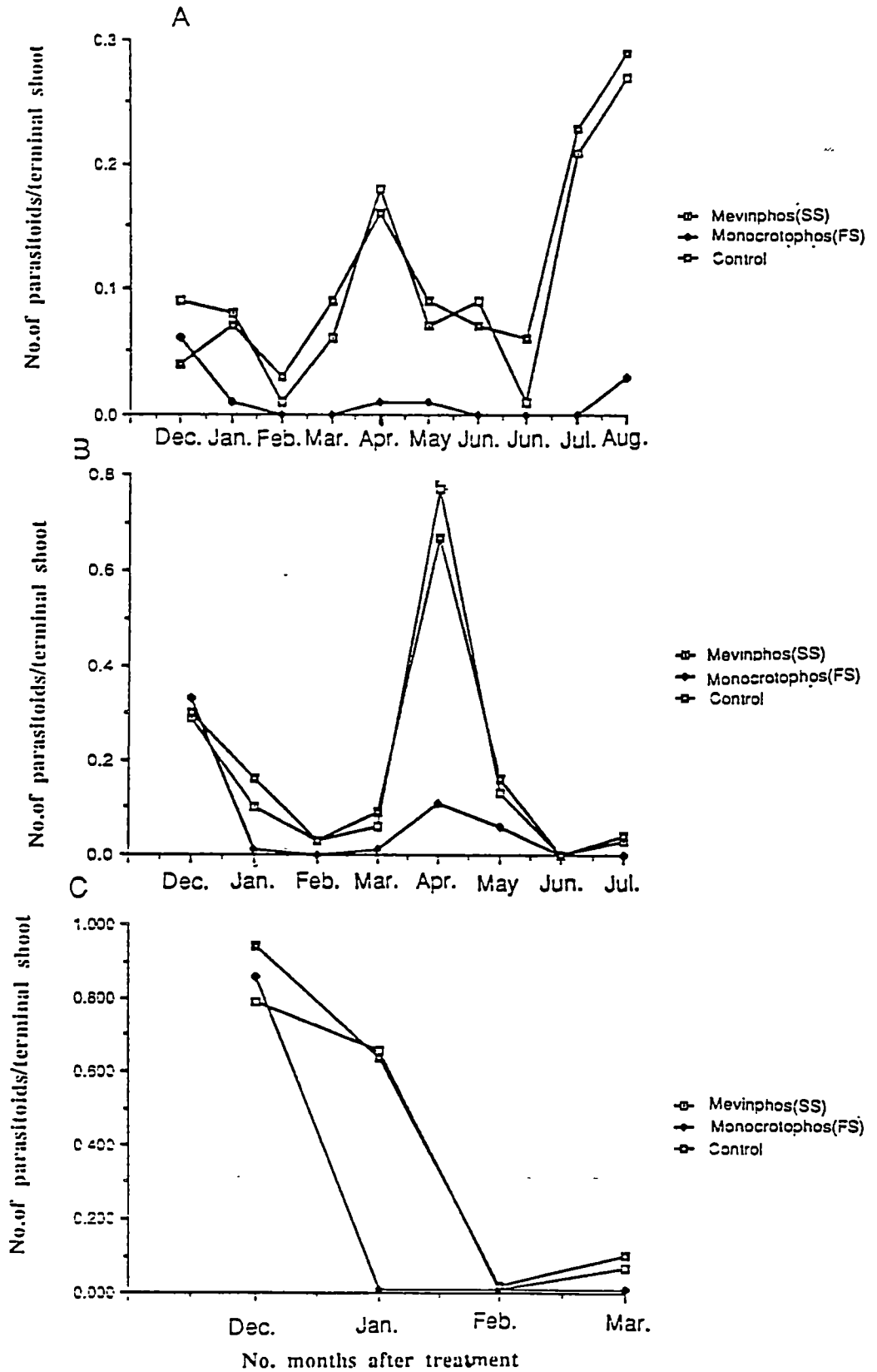


Fig. 64

Effect of application of mevinphos stem spray (mevinphos SS) and monocrotophos foliage spray (monocrotophos FS) on *C.thysanura* parasitoid populations at (A) Copping,1987-88,(B) Huonville,1988-89.and (C) Bakers Beach,1988-89. (Mean results of 70 terminal shoots per treatment).

control plots.

Fig. 65 shows parasitoid emergence from *C. thysanura* mummified nymphs. The mummified psyllid nymphs collected from mevinphos SS plots had significantly higher ($P<0.01$) parasitoid emergence than those collected from the monocrotophos FS plots, but did not differ significantly ($P>0.05$) from those collected from the unsprayed plots, indicating that mevinphos SS conserved the parasitoids.

Table 81,82 and 83 give the mean per cent parasitoid emergence from *C. thysanura* mummified nymphs collected seven days after treatment from mevinphos SS, monocrotophos FS and control plots at Copping,Huonville and Bakers Beach respectively. The mean parasitoid emergence at Copping were 94.6, 16.7 and 95.7 per cent, respectively; at Huonville, 96.8, 12.5 and 97.1 per cent, respectively; and,at Bakers Beach, 93.7, 0 and 96.1 per cent, respectively indicating greater parasitoid emergence from mevinphos SS plots.

Table 81

Effect of mevinphos stem spray and monocrotophos foliage spray on the per cent parasitoid emergence from mummified *C.thysanura* nymphs and the survival rate of parasitoids at Copping,1987-88

Insecticides/method of placement	Cumulative total (Survival rate) of parasitoids	Mean parasitoid emergence (Per cent)
Mevinphos stem spray	0.98a	94.60
Monocrotophos foliage spray	0.06b	16.70
Control (Not sprayed)	1.09a	95.70

Lsd(0.05)=0.12; Lsd(0.01)=0.16

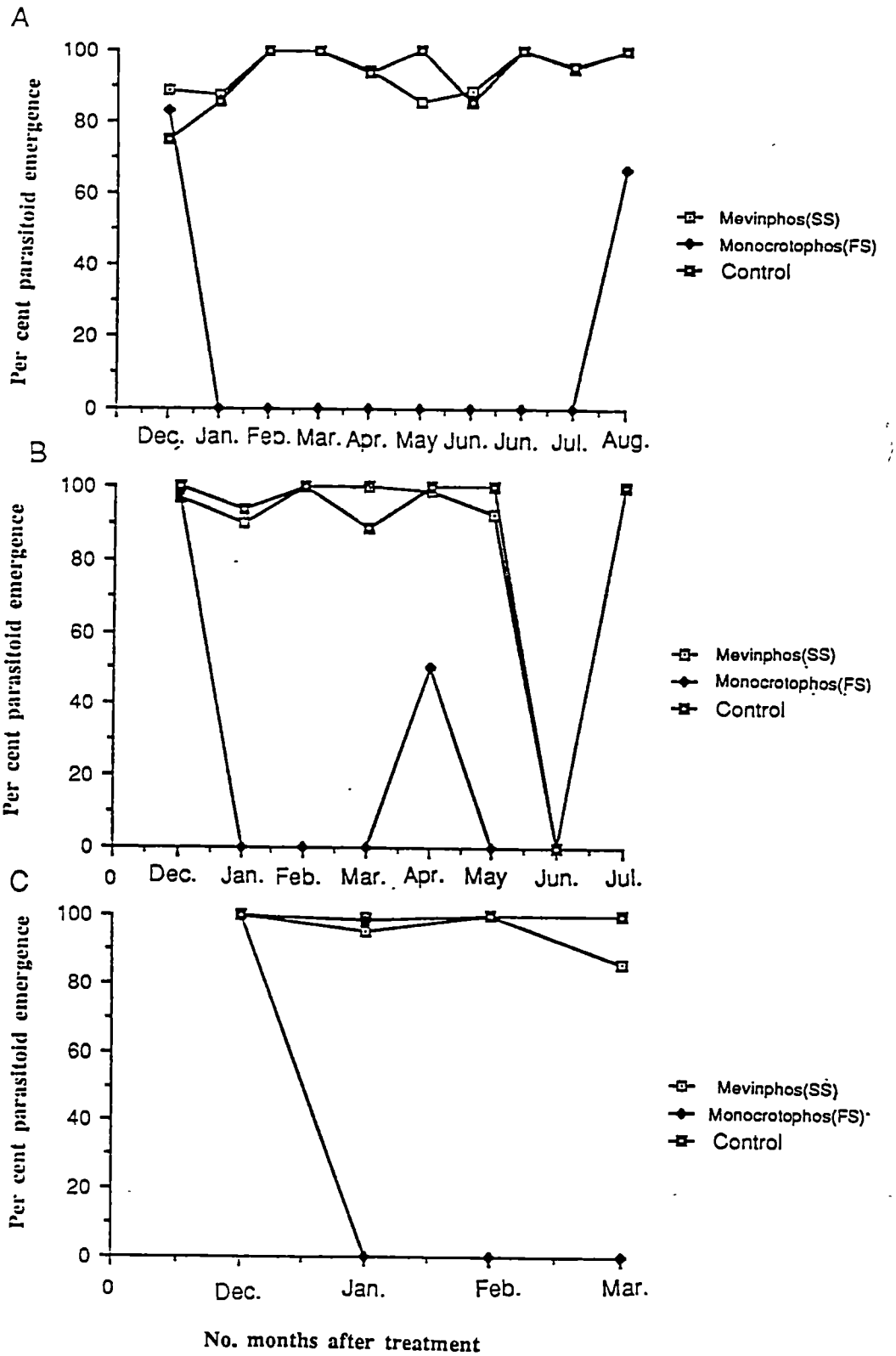


Fig. 65

Effect of mevinphos stem spray (mevinphos SS) and monocrotophos foliage spray (monocrotophos FS) on the per cent parasitoid emergence from *C.thysanura* mummified nymphs on boronia plants at (A) Copping,1987-88,(B) Huonville,1988-89,and (C) Bakers Beach.1988-89.

Table 82

Effect of mevinphos stem spray and monocrotophos foliage spray on the per cent parasitoid emergence from mummified *C.thysanura* nymphs and the survival rate of parasitoids at Huonville,1988-89.

Insecticide/method of placement	Cumulative total (Survival rate) of parasitoids	Mean parasitoid emergence (Per cent)
Mevinphos stem spray	1.12a	96.80
Monocrotophos foliage spray	0.19b	12.50
Control (Not sprayed)	1.14a	97.10

Lsd(0.05)=0.14; Lsd(0.01)=0.19

Means followed by the same letters are not significantly different,P>0.05,Duncan's multiple range test.

Table 83

Effect of mevinphos stem spray and monocrotophos foliage spray on the per cent parasitoid emergence from mummified *C.thysanura* nymphs and the survival rates of parasitoids at Bakers Beach,1988-89.

Insecticides/method of placement	Cumulative total (Survival rate) of parasitoids	Mean parasitoid emergence (Per cent)
Mevinphos stem spray	0.74a	93.70
Monocrotophos foliage spray	0.03b	0.00
Control (Not sprayed)	0.76a	96.10

Lsd(0.05)=0.19; Lsd(0.01)=0.26

Means followed by the same letter are not significantly different,P>0.05,Duncan's multiple range test.

3.2.5.3 Effect of treatment applications on the growth of boronia plants

The effects of mevinphos SS and monocrotophos FS on the growth of boronia plants at Copping, Huonville and Bakers Beach are shown in Fig. 66. Plants which received either mevinphos SS or monocrotophos FS produced more new nodes per terminal shoot ($P<0.01$) than plants which were left unsprayed.The difference in growth of plants which received either mevinphos SS or monocrotophos FS was not significant ($P>0.05$)(Fig.66 and Tables 84 and85)

It is evident from Fig. 66 that plants sprayed with either mevinphos SS or monocrotophos FS produced 1.65 and 1.74 times more new nodes at Copping; 2.73 and 2.83 times more at Huonville; and 2.71 and 2.75 times more at Bakers Beach than the unsprayed control plants, respectively.

3.2.5.4 Effect of treatment applications on flower and oil yield

The numbers of flowers formed per terminal shoot in mevinphos SS and monocrotophos FS plots at both Copping and Huonville are shown in Tables 84 and 85.

Table 84

Effect of mevinphos stem spray and monocrotophos foliage spray on the production of new nodes and flowers on Boronia plants and the percent oil yield at Copping, 1987-88.

Insecticides/method of placement	Mean no.of flowers formed per terminal shoot at the of study	Mean no.of new nodes formed per terminal shoot at the end of study	Mean oil yield(fresh wt basis) (Per cent)
Mevinphos stem spray	32.00a	16.00a	0.62a
Monocrotophos foliage spray	33.80a	16.90a	0.71b
Control (Not sprayed)	19.40b	9.70b	0.48c

Mean no.of flowers/terminal shoot: Lsd(0.05)=2.38; Lsd(0.01)=3.26
Per cent Oil yield(fresh weight basis) : Lsd(0.05)=0.07; Lsd(0.01)=0.10
No.of new nodes/terminal shoot: Lsd(0.05)=3.43; Lsd(0.01)=4.71
Means within columns followed by the same letter are not significantly different, Duncan's multiple range test.

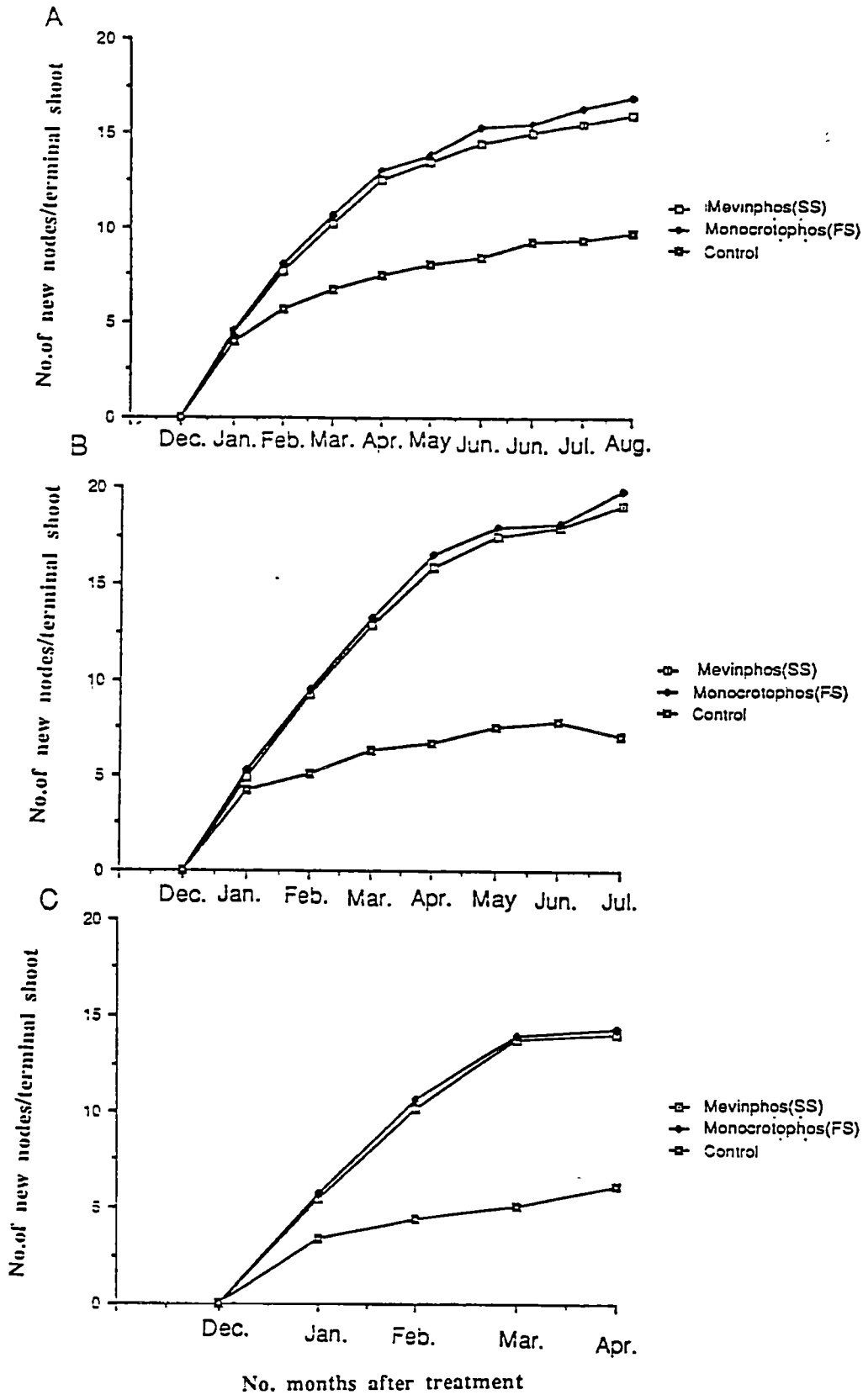


Fig. 66

Effect of mevinphos stem spray(mevinphos SS) and monocrotophos foliage spray (monocrotophos FS) on the growth (new nodes per terminal shoot) of boronia plants at (A) Copping,1987-88,(B) Huonville.1988-89,(C) Bakers Beach.1988-89. (Mean results of 10 replicates per treatment).

Two flowers per node were observed on all plants in the study plots. At Copping, mevinphos SS and monocrotophos FS plants produced 32.00 and 33.80 flowers per shoot, respectively, compared with 19.40 flowers per shoot on control plants (Table 84). The difference between the numbers of flowers per shoot produced in mevinphos SS and monocrotophos FS plots was not significantly different (P>0.05). However, there was a significant difference (P<0.01) between the number of flowers per terminal shoot on sprayed and unsprayed plants (Table 84).

Table 85

Effect of mevinphos stem spray and monocrotophos foliage spray on the production of new nodes and flowers on Boronia plants at Huonville,1988-89.

Insecticides/method of placement	Mean no.of new nodes per terminal shoot at the end of study.	Mean no.of flowers per terminal shoot at the end of study.
Mevinphos stem spray	19.10a	38.20a
Monocrotophos foliage spray	19.80a	39.60a
Control (Not sprayed)	7.00b	14.00b

No.of new nodes/terminal shoot: Lsd(0.05)=3.22; Lsd(0.01)=4.42

No.of flowers/terminal shoot: Lsd(0.05)=3.24; Lsd(0.01)=4.44

Means within column followed by the same letter are not significantly different,P>0.05 Duncan's multiple range test.

Similar results were recorded at Huonville with both mevinphos SS and monocrotophos FS plots producing 38.20 and 39.60 flowers per shoot, respectively, significantly different (P<0.01) from 14.00 flowers per shoot produced by unsprayed plants.

The per cent oil yield of flowers harvested from sprayed and unsprayed plants is also given in Table 84. The monocrotophos FS plots had the highest per cent oil yield (0.71) followed by mevinphos SS plots (0.62) and the unsprayed plot had the lowest oil yield (0.48). The difference between oil yields differed significantly ($P<0.05$) between treatments and the control plots.

The total weights of flowers harvested from each treated plot are given in Table 86 (Copping) and Table 87 (Huonville). The total flower yield (in kilogrammes) was equal in the monocrotophos FS and mevinphos SS plots and was significantly greater ($P<0.01$) than the weight of flowers from the unsprayed plots at both Copping and Huonville.

Table 86

Effect of insecticide sprays on boronia flower yields at Copping,1987-88.(Mean of 7 replicates per treatment).

Treatments	Mean flower yield (kg)
Mevinphos stem spray	9.14a
Monocrotophos foliage spray	9.49a
Control (Not sprayed)	5.54b

Lsd(0.05)=0.82; Lsd(0.01)=1.15

Table 87

Effect of insecticide sprays on boronia flower yields at Huonville,1988-89.(Mean of 7 replicates per treatment).

Treatments	Mean flower yield (kg)
Mevinphos stem spray	5.02a
Monocrotophos foliage spray	5.41a
Control (Not sprayed)	2.78b

Lsd(0.05)=0.70; Lsd(0.01)=0.99

Means followed by the same letter are not significantly different $P>0.05$ Duncan's multiple range test.

3.2.5.5 Economics of control programmes.

Comparisons of the control economics of the boronia crops receiving mevinphos SS, representing an integrated pest management programme with the monocrotophos FS, representing a conventional chemical control programme, are shown in Table 88. Gross profit was highest in plots that received monocrotophos FS ($1,173.95) followed by mevinphos SS plots ($1,015.68) with the control plots recording the lowest return ($488.49) (Table 88). After subtracting the cost of insecticide applications from the gross profit, there was a positive nett gain of $1,044.18 in the monocrotophos FS plots, $889.40 in the mevinphos SS plots with the control plots returning $488.49 (Table 88). The gain from monocrotophos FS was $555.69 and for mevinphos SS, $400.91 (Table 88). The benefit to cost of insecticide ratios applied were greater than one (>1) in both treated plots with monocrotophos FS,4.3:1 and mevinphos SS, 3.2 : 1 (Table 88).

Comparison of flower and oil yields and control economics of commercial boronia crops of a grower at Copping before and after the adoption of the IPM programme are shown in Tables 89 and 90. The flower yield when the farmer was using demeton-S-methyl ten times a season to control *C. thysanura* was 471.40 kg and the per cent oil yield was 0.55 (Table 89). The flower yield when the grower adopted the IPM programme increased to 1,500 kg with an oil yield of 0.58 (Table 90).

Gross profit when demeton-S-methyl was used was $6,693.88 and the nett gain (after subtracting the cost of insecticide application) was $6,273.28. Therefore the gain from the use of demeton-S-methyl was $3,780.46 (Table 89).

The gross profit after adopting the IPM programme was $21,885.00 and the nett gain was $21,560.00 (Table 90). The gain to the grower from the IPM programme was $11,866.33 (Table 90). In comparison to no chemical control, the benefit to cost of treatment applications were 9:1 when demeton-S-methyl was used (Table 89) and 36.6 :1 when the grower adopted the IPM programme (Table 90). Thus the IPM strategy was 4 times profitable than the conventional chemical control.

Table 88

Comparison of flower and oil yield and control economics of commercial boronia crops receiving conventional chemical and Integrated Pest Management programmes at Copping 1987-88.(Table as below,but experimental plot).

A. Insecticide used[b]	Flower yield (kg)	Oil yield (Per cent)	Gross[c] profit $	Cost of[d] insecticide application $	Nett[e] gain $	Gain from[f] insecticide	Benefit : Cost[g] ratio
Mevinphos stem spray (IPM programme)	64.0	0.62	1015.68	126.28	889.40	400.91	3.2:1 >1
Monocrotophos foliage spray (Chemical control)	66.40	0.71	1173.95	129.77	1044.18	555.69	4.3:1 >1
Control (Not sprayed)	38.80	0.48	488.49	0	488.49	-	-

A=Based on Australian dollar (1990); b=Insecticides sprayed at 0.02% a.i;

c=Based on Tasmanian Development Authority (Essential Oil Group) estimated price per kilogram of flowers(Tax and labour inclusive).

1987-88

Oil yield (Per cent)	Price per kg of flowers $	Price/kg of flowers (excluding picking costs) $
0.48	17.59	12.59
0.55	19.20	14.20
0.58	19.59	14.59
0.62	20.87	15.87
0.70	22.65	17.65
0.71	22.78	17.68
0.76	23.82	18.82

d=Cost of insecticide sprays and labour= 4 hours each was used in the application of both mevinphos and monocrotophos

[Current award rate (casual) = $10.00/hr

[Cost of labour for 4 hours = $40.00 per application

Therefore, 3 applications in a season = $120.00

[Cost of mevinphos for the season spraying at 0.02% a.i = $6.28

[Total cost of mevinphos application(Labour inclusive) = $126.28

[Cost of monocrotophos for the season spraying at 0.02% a.i = $9.77

[Cost of labour for 4 hours spraying monocrotophos = $120.00

[Total cost of monocrotophos application(labour inclusive) = $129.77

e= Gross profit - Cost of insecticide application; f= Nett gain of treatment - Nett gain of control

g = Gain from insecticide + Cost of insecticide.

Table 89

Comparison of flower and oil yield and control economics of a 4 ha commercial boronia crop receiving conventional chemical control,at Copping,1986-87.

Insecticide used	Flower yield (kg)	Oil yield (Per cent)	Gross profit ($)	Cost of spray ($)	Nett gain ($)	Gain from insecticide	Benefit to Cost ratio
Demeton-S-methyl (Foliage spray)	471.40	0.55	6693.88	420.60	6273.28	3780.46	9:1
Control (Not sprayed)	198.00	0.48	2492.82	0	2492.82		

Cost of insecticides

Cost of 1,000ml of Demeton-S-methyl	= $42.15
Rate of Demeton-S-methyl application as used by Grower	= 400ml/ha
No.of applications per season	= 10
Therefore volume of insecticide used	= 4,000ml
Total cost of insecticide alone	= $42.15 x 4
	= $168.60
Cost of Labour at $10.00/hr for 14 hours required to spray 4 ha farm	= $140.00
Cost of the use of spraying equipments(including fuel,oil etc) (Grower's estimation)	= $8.00/hr
Therefore, cost for 14 hours	= $8 x 14
	= $112.00
Total cost of insecticide application	= $168+140+112
	= $420.60

Table 90

Comparison of flower and oil yield and control economics of the 4 ha commercial boronia crop receiving Integrated pest management programme (IPM) at Copping, 1987-88.

Treatment	Flower yield (kg)	Oil yield (Per cent)	Gross profit $	Cost of spray ($)	Nett gain ($)	Gain from IPM [a]	Benefit : Cost ratio [b]
IPM programme	1,500	0.58	21885.00	324.37	21560.63	11866.33	36.6: 1.0
Control (Not sprayed)	770	0.48	9694.30	0	9694.30		

Cost of 500ml of mevinphos used in the IPM	= $53.85
Volume of insecticide used for the 4 ha	= 224ml
No.of applications per season	= 3
Total cost of insecticides alone	= $72.37
Cost of labour at $10.00/hr for 14 hours required to spray the 4ha farm	= $140.00
Cost of the use of spraying equipments(including fuel oil etc)	= $8.00/hr
Total cost of the insecticide application	= $72.37+140+112
	= $324.37

a= Nett gain of IPM - Nett gain of control; b= Gain from IPM + Cost of insecticide application

3.2.6 Chemical residue analysis of the boronia oil extract

The results of the residue analyses at detection limits of 0.2ppm and 0.6ppm for mevinphos and monocrotophos respectively, indicated that the boronia oil extracts from each treated plot contained no detectable residue of the organophosphate pesticides used.

4. Discussion

Prior to the start of this study, boronia growers in Tasmania were spraying ten times a season with demeton-S-methyl to control *C. thysanura*, but without success. The reasons for their failure to control the psyllid were:

(1) lack of knowledge of the behaviour, biology and ecology of the pest and its natural enemies

(2) lack of knowledge of the pest's relationship to the host plant that they were trying to protect

(3) poor choice of chemical

(4) improper timing of insecticide spray, and

(5) inappropriate method of chemical application

The growers, in an attempt to control the psyllid, were modifying the environment and unknowingly making it more unfavourable to beneficial insects. They were spraying immediately after flower harvesting and pruning of the terminal shoots in October each year. This period of spray application coincided with the peaks of the egg and early nymphal stages. Demeton-S-methyl is a short, persistent chemical (about 14-21 days according to this study) with little or no ovicidal effect; psyllid eggs hatched within a fortnight of its application. Demeton-S-methyl did not persist long enough to kill the early nymphal stages which hatched from the eggs which were already laid on the plants when the spraying was done. Also, spraying of demeton-S-methyl at the peak of the early nymphal stages killed both the psyllid and its natural enemy complex (especially the parasitoids) breaking the host-natural enemy

relationship which previously existed. Once this synchrony was broken, *C. thysanura* numbers increased rapidly to outbreak levels, each outbreak being followed by another outbreak and spraying was conducted at three or four weekly intervals on all boronia farms in Tasmania. The growers were following routine treatment insecticide schedules to fight *C. thysanura*. Despite ten spray applications within the year, the growers still had reduced flower yields and a lower nett gain. Most growers became frustrated and decided to leave the industry, until this IPM programme was developed.

For *C. thysanura,* the predators and parasitoids are the key mortality factors and their effectiveness in controlling the psyllid decreases as the host density increases, so that to utilise them requires selective pest control intervention that endeavours to curb the number of pest species with minimal effects on the natural enemies. This was achieved using a lower dosage of mevinphos as a stem spray and the application timed to coincide with the peak of *C. thysanura* late nymphal stages. Its use in this way helped to achieve a high degree of ecological selectivity and modified the environment to make it more favourable to the natural enemies, thus increasing their effectiveness. In this study, selectivity was not achieved when mevinphos was used as a foliage spray or when it was applied as a stem spray at the peak of early nymphal stages on the host plant (Tables 62 and 73).

Systemic insecticides applied to the foliage had a general contact effect which resulted in the death of few parasitoids on the host plants and those pupating in the dead mummies. When mevinphos was applied as a stem spray at the peak of the early nymphal stages, however, parasitoids survived (Table 73). This is because during early nymphal development, both parasitised and unparasitised psyllid nymphs were active and feeding and were killed although no direct contact between spray and insect occurred as with a foliage spray. However, when stem application of mevinphos was delayed until the peak of the late nymphal stage, parasitoids which had attacked the psyllids had pupated within the psyllid mummy. This inactive stage was protected from the effects of the systemic spray and the parasitoid survived. The pest population was reduced and parasitoids later emerged to attack early psyllid nymphs of the next generation. As a result the number of insecticide applications was reduced from 10-12

pre study to 3 in the initial stage of the IPM programme, (1987/88). Subsequent levels of parasitism removed the necessity to spray in 1989/90.

Accurate timing of insecticide spray, even foliage sprays, was important for some survival of parasitoids occurred in monocrotophos FS plots sprayed when the plant was infested by late nymphal stages (Table 72). A degree of ecological selectivity had been achieved in chemical sprays through the proper timing of treatments (Ripper 1956; Franz 1961; Wilson and Armbrust 1970; Walker *et al.*1979). The use of systemic insecticides to enhance selectivity, especially against sap-sucking insects such as aphids, mites, thrips, psyllids etc. has been reported (Metcalf 1974). Van den Bosch and Stern (1962) also reported that ecological selectivity of chemicals occurred when placement of the toxic material on the host plant reduced its overall disruption of the agro-ecosystem This view was shared by Wood (1972) who reported that applying the chemical to a restricted part of the environment could help to achieve selectivity.

Apart form mevinphos SS which combined high parasitoid survival with greater *C. thysanura* kill, the other chemicals tested, viz. demeton-S-methyl, dimethoate and monocrotophos, did not combine high *C. thysanura* kills with high parasitoid survivals (Tables 60 and 62) and, therefore, proved to be unsuitable for incorporation into the IPM programme for *C. thysanura* .

Mevinphos SS followed by pruning of the dominant terminal shoots of the host plant was effective in controlling both psyllid eggs and nymphs while having no side effect on the survival of the parasitoid population (Tables 63, 64 and 65). Since *C. thysanura* eggs and nymphal stages are found in the top 15cm of the terminal shoots of the host plant, pruning the terminal shoots causes death of both eggs and nymphs through desiccation. This practice supports the pruning of terminal shoots of boronia plants by boronia growers to increase the numbers of side shoots on the plants later and hence their flower yield.

Looking at the control economics of monocrotophos FS and the IPM plots, it could be seen that monocrotophos FS (conventional chemical spray) gained an extra $1.91 per kg of flowers over the IPM plots (Table 88). This difference was offset by the environmental quality achieved on the IPM plots which combined *C. thysanura*

control with the conservation of natural enemies. The boronia grower at Copping achieved a higher nett gain and a very high benefit to cost ratio of 36.6:1.0 (4 times that of Demeton-S-methyl) when the IPM was adopted in the 1987/88 season (Tables 89 and 90). The benefits achieved in the IPM programme continued to increase as mevinphos stem spray was reduced from three to one in 1989, and in 1990, the population of the natural enemies had increased to a level at which they regulated the psyllid population thus requiring no spray, hence a greater benefit to the grower. In contrast, the continued application of demeton-S-methyl (10 sprays in a year) could have resulted to the development of resistance in the psyllids and also an increase in the residue levels in the boronia oil. Benefit to cost ratios for the use of pesticides are generally considered to return $4 to $5 to the user for every dollar invested (Anonymous 1965). However, Metcalf (1968) reported that the use of DDT in Wisconsin at 2 Ib per acre to control *Leptinotarsa decemlineata* (Say), and *Empoasca fabae* (Harris), increased yields by 68 per cent for a benefit to cost ratio of $29 to $1.

The IPM programme requires an application of three sprays of mevinphos SS within the first year. The three sprays left no detectable residue in the boronia oil at a preharvest interval of five months. However, if boronia plants are sprayed more than three times with the extra spray applications between May and August, the shorter preharvest interval may not be sufficient to guarantee residue levels of either monocrotophos or mevinphos below their detection limits at harvest time. Improper timing of spray applications of either chemical (mevinphos SS and monocrotophos FS) could result in about 8-10 applications per season, so that residue levels below the detection limit could not be guaranteed. For this reason, the practice of spraying at the wrong time (the peak of the early nymphal stage) should be discontinued and the restrictions on the maximum number of applications should be enforced.

Chapter 8

General Discussion and Conclusion

Each preceding chapter contains a full discussion of the subject matter. In this final chapter the relevant findings of the total investigation are brought together to present an appreciation of the development of the project from its inception to completion i.e from the acquisition of basic biological and ecological information through to the development of a cost effective IPM programme. Recommendations are made in the conclusion on the essential requirements necessary to ensure a continuation of successful control together with features requiring further investigations or application.

C.thysanura was described from New Zealand in 1932 by Ferris and Klyver and thought to be of Australian origin. Apart from its taxonomic identity, the insect remained largely unknown in Australia prior to the start of this study.

The increasing demands placed on the Tasmanian essential oil industry, especially for boronia oil, from the world perfumery and flavour industries in the 1980's has led to an intensification in the growth of essential oil plants as plantation crops.

Before the commencement of this study, *C.thysanura* outbreaks had been reported by boronia growers all over the state and the extent of damage to boronia growth and flower yield was so great that most growers had decided to leave the industry. An understanding of the pest insect's behaviour, biology, population ecology and aspects of its host plant relationships and the role of indigenous and exotic natural enemies was essential to the development of an ecologically sound pest management programme if the boronia industry were to be saved.

In the first instance, a mass rearing technique which could provide an abundant and reliable supply of insects in the laboratory had to be established.

Culturing psyllids on a potted boronia plant confined in a ventilated plastic bottle cage was the technique developed that provided a more consistent supply of insects for biological studies than any of the other systems employed eg cellulose acetate cylinder cages (Watmough 1968), perforated plastic bags (Annecke and Cilliers 1963; Moran

and Blowers 1967); and organdie bags (Clark 1962).

The advantages of the technique were that it avoided the wilting associated with cut stems, permitted direct observations, excluded predators, provided a more constant environment and optimal conditions for both plant and insect growth.

The sex ratio of *C.thysanura* was 1:1 in both laboratory culture and field populations which is similar to that reported for *C.albitextura* (Clark 1962), *P.cockerelli* (Pletsch 1947), *P.pyricola* (Burts and Fischer 1967) and *A.genistae* (Watmough 1968).

C.thysanura females were heavier and lived longer than males which agrees with the findings of Clark (1962), Takara *et al.* (1986) and Stechman *et al.* (1987). Mating behaviour was similar to that described for *P.pyricola* by Burts and Fischer (1967) in that males were the aggressors and copulation lasted for 30-40 minutes, when not disturbed, a duration also reported for *C.densitexta* (White, 1970a) and *D.citri* (Pande 1971). The preoviposition period for *C.thysanura* was 5 days followed by the majority of an average of 86 eggs being laid between days 6-10. Females older than 10 days contained very few eggs and were distinctly marked by black transverse bands on the ventral surface of the abdomen.

C.thysanura passed through an egg and five nymphal stages before becoming adult. Mated females laid the majority of their eggs and fertility was ca. 99 per cent. In contrast, unmated females laid only a few infertile eggs. These attributes are similar to those for *P.pyricola* (Burts and Fischer 1967).

During the spring and summer generations, *C.thysanura* females were attracted to yellow traps when reflectance in the 440-480 nm region exceeded 29 per cent of the total reflectance. Females preferentially selected boronia plants with new terminal shoots and laid eggs within the leaf axils with most concentrated in the third and fourth nodes from the apex of these shoots. New terminal shoots differed from the older, harder, dark green foliage in being pale yellow-green and tender. Therefore the softness of new shoots allowed penetration by the ovipositor for full insertion of the egg pedicel ensuring the uptake of water that is essential to egg viability. This requirement was noted also of *P.pyricola* (Moran and Blowers 1967), *C. densitexta* (White 1968a),*C.albitextura* (Clark 1962) and *H.cubana* (Takara *et al.* 1986). In autumn eggs are laid in the flower bracts and sepals.

Clark (1963b) reported that batches of *C.albitextura* eggs attracted other females to oviposit at those sites but no such behaviour was observed in *C.thysanura*. More eggs were laid within the leaf axils of culture plants than in the field but this was related to the fixed number of sites within the culture cage. Experimentally it was shown that numbers of eggs laid per female per shoot decreased as shoot availability increased. Thus the tendency to disperse the placement of eggs among available shoots would act to reduce intraspecific competition.

The morphology and the physical characteristics of the terminal shoot affected both oviposition and nymphal survival. Leaflets of the second, third and fourth nodes were unfurling and enlongating to be essentially parallel to the main stem and at this stage formed a protected site for egg placement. Leaflets at the fifth and subsequent nodes became increasingly lignified and straightened to stand at right angles to the main stem. The preferred sites protected eggs and early nymphs from desiccation.

The relative hardness of the leaflets was identified as the major factor which determined discrimination between cultivars for oviposition. When penetrance, the index of hardness exceeded 80g per mm of leaf thickness oviposition declined. Plants with tender closed shoots (eg HC 142) had 43 times as many eggs as plants with hard open shoots (HC 27) under "free" choice conditions.

Inhibition of oviposition through "hardness" and the absence of a parallel attitude of leaflets to provide protection of eggs and nymphs from desiccation and, perhaps, enemies join those physical and morphological characteristics of plants that have been reported by Clark (1963a); Sorensson and Brewbaker (1984); Catling (1969a); Watmough (1968a); Kogan (1974); Moran (1968) and Moran and Buchan (1975) to protect plants from psyllid attack.

C.thysanura females also laid fewer eggs on previously infested terminal shoots. This deterrance was associated with the active production of honey dew by psyllid nymphs. However, when all these nymphs had developed to adults a further 3 weeks was required for the old leaves to be restored to their original condition and suitable for oviposition. Presumably this lag was due to decontamination of leaf surfaces and restoration of normal turgor of cells.

Conversely, use of nitrogenous fertilizers stimulated plant growth and optimized conditions for oviposition and nymphal (and adult) feeding in comparison to insect activity on unfertilized plants. White (1970b) emphasised the importance of plant

nitrogen to sucking insects and Madsen *et al.* (1963) reported a progressive decline in pear psyllid numbers due to the lower growth performance of abandoned orchards in time.

Psyllids, like aphids, are phloem feeders (Clark 1962; Eyer 1937; Hodkinson 1973a; and Woodburn and Lewis 1973). Toluidine Blue (1%) was used to successfully locate the feeding stylets within phloem and bundle sheath cells.

The effect of continuous feeding on heavily infested boronia plants varied with plant age. Seedling trees could be killed by an average density of 8 nymphs/shoot whereas mature bushes (5 yo) could tolerate infestations of 20 mature nymphs/shoot. Severely affected plants lost turgor, growth ceased and leaves abscissed. Less severe infestations reduced vegetative growth and the initiation and formation of flower buds resulting in fewer flowers and reduced yields of oil.

C.thysanura nymphs, and especially the less active first stages, are unable to feed and survive on mature stems. The migratory activity of nymphs increased from the 1st through to the 5th stage which permitted older nymphs to seek out unoccupied or otherwise favourable shoots. The surface area to volume ratio increased with development and hence potential susceptibility to desiccation as found by Pletsch (1947) and Hodkinson (1974).

Although width of head capsule and number of antennal segments are two of the most common parameters employed to recognise psyllid nymphal stages (K L Taylor pers. comm.) it was found that body length, a third and easier parameter to measure, was highly correlated (r=0.99).

There are three generations of *C.thysanura* per annum with the generation time dependent on temperature. The spring and summer generations had the shortest generation times and autumn/winter the longest. During the onset of cold conditions, eggs are laid not in leaf axils but in the flower bracts and sepals. At this time first to third stage nymphs also migrate to the flower bracts and sepals whereas the fourth and fifth stage nymphs are excluded by size from these sites but develop a dark pigmentation. Although general activity is low during winter the darkly pigmented late nymphal stages must continue to develop by efficiently absorbing any insolation during fine but cool days. Insect survival during winter was favoured by general inactivity, insulation from cold within bracts and sepals and an absence of natural

enemies. In contrast spring and summer conditions were often unpredictable with extreme short-term temperature fluctuations of 20°C. Moreau and Roberts (1985) stated that cold weather alone seldom caused mortality of indigenous insects due to specific adaptations and an inverse relationship between temperature and psyllid numbers was reported by List (1939), Madsen *et al.* (1963), Clark (1964), Moran and Blowers (1967) and Catling (1969). Van der Merwe (1941) noted high mortalities of *T. erytreae* nymphs on hot summer days whereas the insects survived and thrived during the cool winter.

Psyllid populations were examined intensively at a number of locations in Tasmania. Generation budgets were developed from the population data and key mortality factors and processes identified using Varley and Gradwell key factor analysis. It was shown in all locations that the key mortality factors were parasitoids and predators and intraspecific competition for food and space as determined by the quality and quantity of plant resource and psyllid density.

Intraspecific competition also reduced insect's body size and fecundity and resulted in emigration from over exploited host plants. Parasitoid and predator responses to host or prey density resulted in delayed density dependent effects which eventually stabilized psyllid populations at low densities. However, indiscriminate or poorly timed spraying destroyed natural enemies, the key regulatory agencies, and resulted in *C.thysanura* populations growing rapidly to exploit the food resource. This resulted in competition and density induced emigration and a reduction in the size and fecundity of females developing from nymphs left on the exploited plant. These changes reduced feeding pressure so much that shoots regrew and this in turn, provided suitable food for a rapid increase in resident psyllid numbers to occur in the absence of enemies.

Another factor contributing to *C.thysanura* establishment was infestation by the aphid *A. gossypii.* The siphuncular secretions of adult aphids was shown to consist of trans-ß-farnesene a material reported by Kislow and Edwards (1972) to repel several species of aphids and other insects. *C.thysanura* adults increasingly left plants on which aphid numbers were rising. Although the feasibility of protecting boronia using trans-ß-farnesene could not be assessed due to unavailability of synthetic material it does have real potential. Aphids *per se* could not be used for in large

numbers they also severely affect plant growth and flower yield. This is the first time a study has shown the exclusion of psyllids by the presence of another insect.

The age-specificity of recognized mortality factors for *C.thysanura* are summarized in Table 91.

In conclusion this investigation has shown that to grow boronia economically as a plantation crop, pest management must (a) ensure protection of parasitoids and predators to stabilize psyllid numbers and (b) avoid any practice or procedure that could affect stability. Although pruning resulted in a reduction of psyllid infestation per plant failure to remove prunings provided a source of reinfestation.

As discussed earlier, indiscriminate application of insecticides can result in instability with subsequent damage to plants. In such instances and indeed with the development of any outbreak it is necessary to apply an insecticide to reduce numbers below the damage threshold. Results indicate that a selective form of control that preferentially reduces pest numbers with minimal effects to natural enemies was achieved by the application of the systemic material mevinphos to the stems of boronia bushes at less than recommended dosage and at the time when over 60 per cent of the nymphal population consisted of 4th and 5th stages. Only at this time was the majority of parasitoids, which had initially attacked *C.thysanura* in the first to third stages, pupating within the mummified host. Consequently, all actively feeding unparasitized nymphs were potentially susceptible to mevinphos but the inactive parasitoids were not. Furthermore coccinellid and syrphid predators occurred only on the foliage of the host plant and were not significantly affected by mevinphos for stem applications minimized any possible contact effect. In contrast to the 10 insecticide applications per annum prior to the commencement of this study in the 1986/87 season, the IPM programme introduced in 1987/88 resulted in a single application per generation (3 per annum) and the resultant conservation of natural enemies has not necessitated insecticide usage since 1989. That is, it took approximately 2 years or six generations for true stability of the *C.thysanura* population to occur at levels below that causing significant damage to the crops.

The most critical factors in the programme were (a) the use of systemic material, mevinphos at an effective dosage that killed 90 per cent of the nymphs

(b) the application of mevinphos to stems rather than foliage to minimize contact effects

Table 91

Age-specificity of recognized mortality factors for *C.thysanura*

Stage:	Nymphal stages						
Mortality factor	Egg	I	II	III	IV	V	Adult
Quality and Quantity of host plant terminal shoots.	Essential for breeding						Essential for oviposition
High temperature	Egg to stage III nymphs highly susceptible				Behavioural resistance from stages IV to V		Sensitive
Low temperature	Egg to stage III nymphs susceptible				Stage IV and V nymphs not susceptible		Susceptible
Desiccation	Increasing susceptibility from egg to stage V						Tolerant
Suction harvesting of flowers of host plant	All stages affected						
Pruning of terminal shoots of host plant	Egg to stage II nymphs highly susceptible				Stages III to V nymphs susceptible		Not susceptible
Intraspecific competition	Nymphal and adult stages severely affected						
Emigration	Egg and nymphal stages not severely affected						Susceptible
Presence of *A.gossypii*	Egg and nymphal stages not severely affected						Repellance and emigration
Parasitoids	No egg parasitoids recorded		Stages I to V nymphs highly susceptible				No parasitoids recorded
Predators	No egg predators recorded		Nymphal and adult stages highly susceptible				
Puccinia boroneae rust	Oviposition and nymphal habitat destroyed.						

(c) applying mevinphos precisely when the majority of nymphs were in the 4th and 5th nymphal stages and

(d) removal of prunings.

The importance of precise timing of applications to achieve ecological selectivity has been stressed by Ripper (1956), Franz (1961), Wilson and Ambrust (1970) and Walker *et al* (1979). Specific placement of insecticide on the host plant to achieve selectivity was reported by Wood (1972). Removal of prunings has been a traditional objective of good crop hygiene.

Considering the economics of control, the benefit to cost of insecticide ratio of the grower from the IPM programme was $36.60 to $1.00, which was 4 times over the conventional 10 demeton-S-methyl application schedule.

This study recognises the importance of ecological studies as the basis for any pest control strategy. Wood(1972) reported that to develop an ideal pest management programme for key pests, the programme should be based on the study of the pest's population dynamics and full use made of life table and key factor studies. Many entomologists and primary producers decide on pest control without a clear understanding of how to assess populations and recognize key mortality factors resulting in inefficient control.

The concept of IPM calls for the utilisation of all pest control practices in a complementary manner to minimize chemical usage, protect natural enemies and avoid adverse effects on the environment. These objectives were achieved in this study. The study also clearly points out that pesticides must play an important role in pest management systems and that they remain the most powerful general purpose method of pest control. However, to utilize them in pest management systems caution should be taken in choice of chemical, when to apply it and with which application method to be appropriate to the particular situation and to avoid disruption of the whole agroecosystem.

As boronia is grown as a monoculture in Tasmania and no alternative host identified, any mismanagement of the IPM programme developed would lead to a rapid outbreak of psyllids which might require further studies into the pest. Outbreaks of the pest could result from an increase in the number of insecticide sprays which may eventually result in the development of psyllid resistance to the chemicals used and,

furthermore, a residue level below levels of detection could not be guaranteed. For this reason the practice of spraying at the wrong time should be discontinued and panic spraying avoided at least as foliage applications. Continued successful control requires constant attention to detail in population assessment and identification of population change. Although refinements to the programme will occur it is essential that the consequences of any change be considered for there are no shortcuts in the control of insect populations.

The basic elements of IPM are not new. Man must be patient and study the pest situation in detail in order to understand the behaviour, biology and ecology of the pest before appropriate methods of control can be developed.

This was stated by Loudon in 1834: " 3040. *Insects are the most numerous, as well as the most destructive, foes to which gardens are exposed.* The species are so many, and their devastation so varied, that, without some acquaintance with their scientific classification, and a correct knowledge of their habits and economy, their operations can neither be understood nor effectually counteracted. It is, therefore, the duty, not only of the intelligent agriculturalist, but also of the gardener, to acquire both these branches of information. The first may be learned from books, but the second can only be gained by attention to the insects themselves, to the particular changes they undergo, and to the effects they produce. The generality of gardeners are deplorably ignorant on this subject; and hence arises the misapplication of remedies, the consequent destruction of plants and fruits, and the persecution of birds, and even insects, that are beneficial to gardening operations."

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Appendix 1

Data of the response of *C.thysanura* adults to colour enamels in a boronia farm at Kingston,1986-1987.(Mean of 8 replicates).

Colour enamels	% total reflectance	Mean 10 days trap catch
Full Yellow (Y)	31.3	16.47a
Full White (W)	27.4	0.61b
3 Y:1 W	29.4	11.90a
1 Y:1 W	27.9	3.43b
1 Y:3W	27.4	1.13b

Mean trap catches {Lsd(0.05)=7.01;Lsd(0.01)=9.55}

Means within a column followed by the same letter are not significantly different at P>0.05,Duncan's multiple range test.

Analysis of variance table.

Source of variance	Degrees of freedom	Sum of squares	Mean square variance	F
Treatments	4	43464.393	10866.098	227.456**
Replications	7	2014.193	287.742	
Error	28	1337.622	47.772	
Total	39	46816.208	11201.612	

Appendix 2

Data on the effect of *C.thysanura* on the number of new nodes formed per terminal shoot relative to uninfested boronia plants under glasshouse conditions.(Mean of 8 replicates per treatment).

Days of post treatment counts	Infested plants	Uninfested plants
0	5.00a	5.00a
14	5.88a	5.63a
28	6.75a	6.75a
42	7.38a	8.38a
56	8.13a	11.13a
70	9.38a	13.38a
84	10.13a	14.50a
98	10.13a	15.50b
112	10.13a	17.13b
126	10.13a	19.00b
140	10.13a	20.00b
154	10.13a	21.88b
Total	103.30	158.28

Lsd(0.05)=6.30; Lsd(0.01)=9.31

Means within rows followed by the same letter are not significantly different(P>0.05),Duncan's multiple range test.

Analysis of variance table

Source of variance	Degrees of freedom	Sum of squares	Mean square variance	F
Treatments	1	1003.755	1003.75	35.465**
Replicates	7	207.328	29.618	
Error	7	198.12	28.303	
Total	15	1409.203	1061.676	

Appendix 3

Data on the effect of insecticide sprays on the number of C.thysanura nymphs per terminal shoot of boronia plants during the period December,1987-August,1988. (Mean of 70 terminal shoots per treatment.

No.of months after treatment	Monocrotophos sprayed (protected) plot	Unsprayed plot
December 1987	7.64a	5.36a
January 1988	0.83a	4.76a
February "	0.29a	14.59b
March "	3.49a	17.33b
April "	3.64a	12.30b
May "	1.50a	14.56b
June,2nd 1988	1.16a	13.31b
June,30th "	1.17a	17.27b
July "	1.56a	18.86b
August "	2.34a	18.16b
Total	23.62	1365.00

Lsd(0.05)=5.72; Lsd(0.01)=8.66

Means within rows followed by the same letters are not significantly different (P>0.05); Duncan's multiple range test.

Analysis of variance table

Source of variance	Degrees of freedom	Sums of squares	Mean square variance	F
Treatments	1	4458.986	4458.986	233.535**
Replicates	6	238.243	39.707	
Error	6	114.561	19.093	
Total	13	4811.790	4517.786	

Appendix 4

Data on the mean number of new nodes formed per terminal shoot on sprayed and unsprayed plots.(Mean of 10 replicates per treatment).

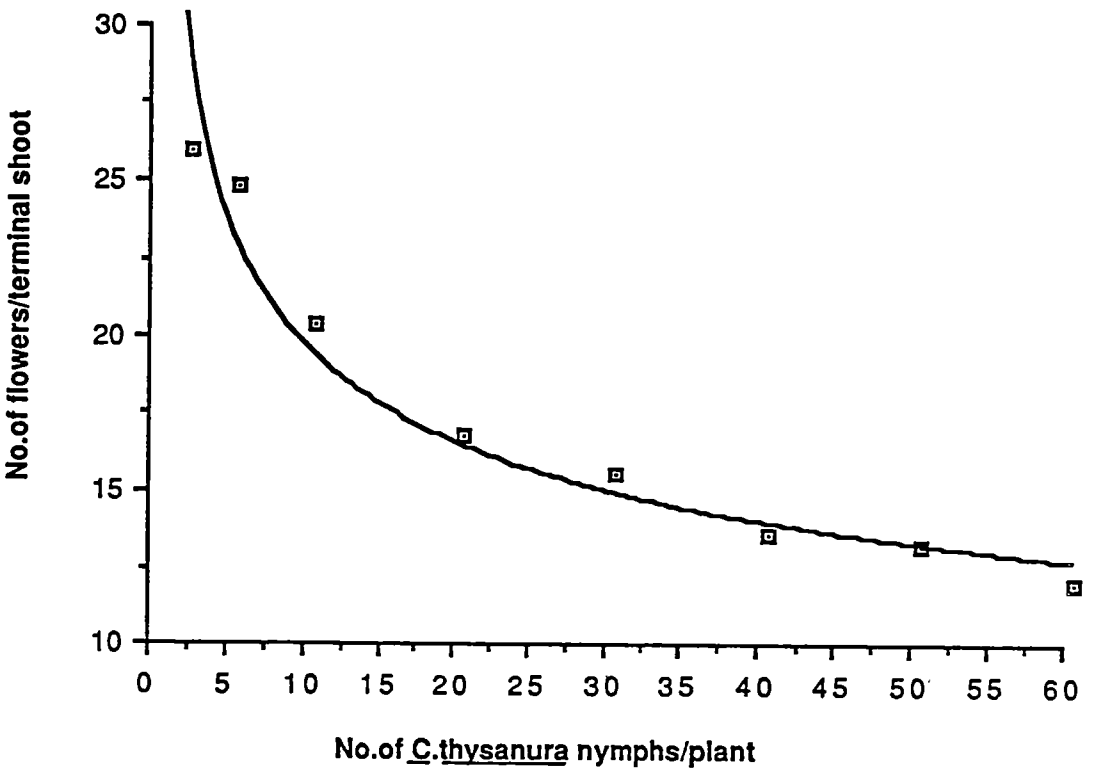
No.of months after treatment		Monocrotophos sprayed (protected) plot	Unsprayed plot
December	1987	0a	0a
January	1988	4.50a	3.90a
February	"	7.70a	5.60a
March	"	10.60a	6.70a
April	"	13.00a	7.40b
May	"	13.80a	8.00b
June,2nd	"	15.30a	8.40b
June,30th	"	15.50a	9.20b
July	"	16.30a	9.30b
August	"	16.90a	9.70b
Total		113.60	68.20

Lsd(0.05)=4.02; Lsd(0.01)=5.78

Means within rows followed by the same letter are not significantly different(P>0.05),Duncan's multiple range test.

Analysis of variance table

Source of variance	Degrees of freedom	Sums of squares	Mean square variance	F
Treatments	1	1030.58	1030.58	65.263**
Replicates	9	178.48	19.831	
Error	9	142.12	15.791	
Total	15	1351.18	1066.202	



Appendix 5

Effect of *C.thysanura* on boronia flower production.

Appendix 6

The mean number of new nodes,flowers and dead terminal shoots of boronia plants infested with varying population densities of *C.thysanura* nymphs under glasshouse conditions during the period April,1988-June,1988. (Mean of 5 replicates)

	No.of *C.thysanura* nymphs/plant	
	2	5
No.of nodes formed/terminal shoot	12.80	12.40
No.of flowers/terminal shoot	25.60	24.80
No.of dead terminal tips/plant	0	0.20

Appendix 7

The duration of the egg and nymphal stages of *C.thysanura* at Copping during the period 1986-89 derived from day degrees using the results of a glasshouse study of *C.thysanura* stage duration at a mean daily temperature of 19°C. In the first row,the right hand figures in brackets are the durations of each stage at a mean daily temperature of 19°C in the glasshouse.

Year	Generation	Mean duration of stage (days)						Total duration	Average daily
		Egg stage	1st stage	2nd stage	3rd stage	4th stage	5th stage	Egg- 5th stage	mean temp. (°C)
1986	III	19.43(11.45)	7.30(4.28)	7.50(4.40)	8.53(5.00)	11.67(6.84)	14.43(8.46)	68.86(40.46)	11.14
1987	I	14.04	5.25	5.39	6.13	8.39	10.37	49.57	15.50
	II	29.92	11.19	11.50	13.07	17.88	22.11	105.67	7.27
	III	14.39	5.38	5.53	6.29	8.60	10.63	50.82	15.12
1988	I	12.20	4.56	4.69	5.33	7.29	9.02	43.09	17.83
	II	24.17	9.04	9.29	10.56	14.44	17.86	85.36	9.00
	III	16.16	6.04	6.21	7.06	9.66	11.94	57.07	13.46
1989	I	11.45	4.28	4.40	5.00	6.84	8.46	40.46	19.00
	II	25.18	9.41	9.68	11.00	15.04	18.60	88.91	8.64

Appendix 8

The duration of the egg and nymphal stages of *C.thysanura* at Kingston during the period 1986-89 derived from day degrees using the results of a glasshouse study of the psyllid's stage duration at a mean daily temperature of 19°C. In the first row the right hand figures in brackets are the durations of each stage at a mean daily temperature of 19°C in the glasshouse.

Year	Generation	Mean duration of stage (days)						Total duration	Average daily
		Egg stage	1st stage	2nd stage	3rd stage	4th stage	5th stage	Egg-5th stage	mean temp. (°C)
1986	III	17.06(11.45)	6.38(4.28)	6.56(4.40)	7.45(5.00)	10.19(6.84)	12.61(8.46)	60.25(40.46)	12.75
1987	I	14.67	5.48	5.64	6.41	8.76	10.84	51.80	14.83
	II	26.02	9.73	10.00	11.36	15.55	19.23	91.89	8.36
	III	15.74	5.88	6.05	6.87	9.40	11.63	55.57	13.82
1988	I	13.79	5.15	5.30	6.02	8.24	10.19	48.69	15.78
	II	24.17	9.04	9.29	10.56	14.44	17.86	85.36	9.00
	III	15.64	5.85	6.01	6.83	9.34	11.56	55.23	13.91
1989	I	13.19	4.93	5.07	5.76	7.88	9.74	46.57	16.50
	II	27.19	10.17	10.45	11.88	16.25	20.09	96.03	8.00

Appendix 9

The duration of the egg and nymphal stages of *C.thysanura* at (A) Summerleas and (B) Howden derived from day degrees using the results of a glasshouse study of the psyllid's stage duration at a mean temperature of 19°C. In the first row,the right hand figures in brackets are the durations of each stage at a mean daily temperature of 19°C in the glasshouse.

Year	Generation	Mean duration (days)						Total duration	Average daily
		Egg stage	1st stage	2nd stage	3rd stage	4th stage	5th stage	Egg-5th stage	mean temp. (°C)
(A) Summerleas:									
1988	III	13.69(11.45)	5.12(4.28)	5.26(4.40)	5.98(5.00)	8.18(6.84)	10.12(8.46)	48.35(40.46)	15.89
1989	I	11.76	4.40	4.52	5.14	7.03	8.69	41.54	18.50
	II	26.37	9.86	10.13	11.52	15.75	19.48	93.11	8.25
(B) Howden:									
1988	III	13.51	5.05	5.19	5.90	8.07	9.98	47.70	16.10
1989	I	12.09	4.52	4.64	5.28	7.22	8.93	42.68	18.00
	II	22.50	8.41	8.65	9.82	13.44	16.62	79.44	9.67

Appendix 10

The duration of the egg and nymphal stages of *C.thysanura* at (A) East Sassafras ana (B) Bakers Beach derived from day degrees using the results of the glasshouse stage duration study of the psyllid at 19°C.In the first row,the right hand figures in brackets are the durations of each stage at a mean daily temperature of 19°C in the glasshouse.

Year	Generation	Mean duration of stage (days)						Total duration	Average daily
		Egg stage	1st stage	2nd stage	3rd stage	4th stage	5th stage	Egg-5th stage	mean temp. (°C)
(A) East Sassafras:									
1988	III	14.55(11.45)	5.44(4.28)	5.59(4.40)	6.36(5.00)	8.69(6.84)	10.75(8.46)	51.38(40.46)	14.95
1989	I	13.15	4.91	5.05	5.74	7.85	9.71	46.41	16.55
(B) Bakers Beach:									
1988	III	14.31	5.35	5.50	6.25	8.55	10.58	50.54	15.20
1989	I	12.63	4.72	4.86	5.52	7.55	9.33	44.61	17.22

Appendix 11

Data of the comparison of the time of occurrence of the various predators with those of the nymphs and adults of *C.thysanura* on boronia plants at Copping,1987-89.

Year	Month	Total no.of psyllids (nymphs+adults) per terminal shoot in samples	Total no.per sweep				
			Syrphus sp.	True spiders	Coccinellids	Trombidiid mites	Total no per sweep
1987	July	8.19	0	0.210	0.040	0	0.25
	August	8.36	0	0.250	0.006	0	0.26
	September	12.68	0.007	0.210	0.010	0	0.23
	October	10.01	0.010	0.150	0.006	0	0.17
	November	6.60	0.003	0.040	0	0	0.04
	December	1.91	0	0.010	0	0	0.010
1988	January	1.52	0	0.130	0.010	0.003	0.14
	February	4.91	0	0.180	0.010	0	0.19
	March	6.88	0	0.290	0.030	0.007	0.33
	April	6.72	0	0.360	0.040	0.020	0.42
	May	9.69	0	0.340	0	0.003	0.34
	June	13.68	0	0.130	0.010	0	0.14
	July	14.89	0	0.120	0.010	0.010	0.14
	August	17.48	0	0.120	0.080	0	0.20
	September	18.39	0.020	0.150	0.070	0	0.24
	October	14.95	0.030	0.040	0.030	0.003	0.10
	November	11.44	0.010	0.060	0.003	0.003	0.08
	December	9.44	0.003	0.090	0.020	0	0.11
1989	January	14.15	0.003	0.100	0.017	0	0.12
	February	14.14	0	0.190	0.010	0.010	0.21
	March	9.34	0	0.230	0.030	0	0.26
	April	8.60	0	0.280	0.020	0.030	0.33
	May	3.22	0	0.200	0.003	0.020	0.22
	June	1.24	0	0.090	0	0.040	0.13
Total		228.43	0.086	3.97	0.455	0.149	4.66

Appendix 12

Data of the time of occurrence of the various predators with those of the nymphs and adults of *C.thysanura* on boronia plants at Kingston,1987-89.

Year	Month	Total no.of psyllids (nymphs+adults) per terminal shoot in samples.	Total no.per sweep				
			Syrphus sp.	True spiders	Coccinellids	Trombidiid mites	Total no.per sweep.
1987	Jul.	9.54	0	1.26	0.060	0	1.32
	Aug.	8.84	0	1.27	0.060	0	1.33
	Sept.	9.91	0	0.34	0.010	0	0.35
	Oct.	9.09	0	0.32	0.030	0	0.35
	Nov.	7.91	0.003	0.19	0.020	0.020	0.23
	Dec.	5.15	0.003	0.11	0.010	0.020	0.14
1988	Jan.	2.74	0	0.11	0	0.010	0.12
	Feb.	5.79	0	0.16	0.060	0.030	0.25
	March	9.29	0	0.21	0	0.060	0.27
	April	6.05	0	0.78	0	0.040	0.82
	May	4.09	0	1.42	0	0.050	1.47
	June	5.74	0	0.74	0.010	0.010	0.76
	Jul.	4.09	0	0.99	0	0.030	1.02
	Aug.	6.50	0	1.04	0.010	0.003	1.05
	Sept.	4.07	0	0.69	0.040	0.020	0.75
		Oct.	4.81	0.03	0.560	0.010	0.60
	Nov.	4.67	0.01	0.14	0.003	0.100	0.25
	Dec.	3.76	0	0.12	0	0.050	0.17
1989	Jan	1.72	0	0.14	0.003	0.020	0.14
	Feb.	4.01	0	0.25	0.003	0.060	0.31
	March	4.88	0	0.45	0	0.040	0.49
	April	4.51	0	0.73	0.010	0.080	0.82
	May	1.50	0	0.61	0.010	0.030	0.65
	June	1.48	0	0.39	0.010	0.010	0.41
Total		130.14	0.046	13.02	0.349	0.693	14.108

Appendix 13

Data on the effect of crowding of *C.thysanura* nymphs on the duration of the developmental stages.

Population density	Duration of developmental period (days)
10	45.31
20	47.13
30	48.55
40	49.56
50	51.75
60	50.02
Total	292.32
Mean	48.72

Analysis of variance table

Source of variance	Degrees of freedom	Sum of squares	Mean square variance	F
Treatments	5	128.8276	25.7655	14.535**
Replicates	4	14.2514	3.5629	2.01
Error	20	35.4520	1.7726	
Total	29	178.5310	31.101	

Lsd(0.05)= 1.757; Lsd(0.01)= 2.396

Appendix 14

Data on the effect of crowding on the mortality of *C.thysanura* nymphs

Population density	Nymphal mortality (Per cent)
10	2.0
20	10.0
30	21.30
40	34.0
50	35.6
60	36.0
Total	139.90
Mean	23.20

Analysis of variance table

Source of variance	Degrees of freedom	Sum of squares	Mean square variance	F
Treatments	5	5701.4667	1140.2933	49.1534**
Replicates	4	178.9347	44.7337	1.9283
Error	20	463.9733	23.1987	
Total	29	6344.3747	1208.2257	

Lsd(0.05)= 6.35; Lsd(0.01)= 8.67

Appendix 15

Data on the effect of crowding of *C.thysanura* adult females on total fecundity .

No.of females/terminal shoot	Total no.of eggs
1	323
2	452
3	459
4	500
5	601
6	721
Total	3056
Mean	509.33

Analysis of variance table

Source of variance	Degrees of freedom	Sum of squares	Mean square variance	F
Treatments	5	6689.2185	1337.8437	43.8574**
Replicates	4	36.3188	9.0797	0.2977
Error	20	610.0886	30.5044	
Total	29	7335.6259	1377.4278	

Lsd(0.05)= 7.29; Lsd(0.01)= 9.94

Appendix 16

Data on the effect of crowding of *C.thysanura* adult females on the number of eggs laid per female.

Number of females/terminal shoot	No.of eggs/female
1	64.60
2	45.20
3	30.61
4	25.00
5	24.04
6	24.03
Total	213.48
Mean	35.38

Analysis of variance table

Source of variance	Degrees of freedom	Sum of squares	Mean square variance	F
Treatments	5	18766.6666	3753.3333	13.6950**
Replicates	4	181.4667	45.3667	0.1655
Error	20	5481.3334	274.0667	
Total	29	24449.4667	4072.7667	

Lsd(0.05)= 21.84; Lsd(0.01)= 29.79

Appendix 17

Data on the effect of quantity of terminal shoots on the number of eggs laid per terminal shoot of boronia plants by *C.thysanura* females.

No.of terminal shoots available for oviposition.	Mean no.of eggs/terminal shoot
1	106.00
2	150.60
3	157.60
4	162.20
5	163.20
Total	739.60
Mean	147.92

Analysis of variance table

Source of variance	Degrees of freedom	Sum of squares	Mean square variance	F
Treatments	4	11477.8398	2869.45995	7.8089**
Replicates	4	1864.6399	466.159975	1.2686
Error	16	5879.3601	367.4600	
Total	24	19221.8398	3703.0799	

Lsd(0.05)= 25.70; Lsd(0.01)= 35.41

Appendix 18

Data on the effect of the quantity of terminal shoots on the number of eggs laid by *C.thysanura* females.

No.of teminal shoots available for oviposition.	No.of eggs per female
1	53.00
2	75.30
3	78.80
4	81.10
5	81.60
Total	369.80
Mean	73.96

Analysis of variance table

Source of variance	Degrees of freedom	Sum of squares	Mean square variance	F
Treatments	4	2869.460	717.365	7.8089**
Replicates	4	466.160	116.540	1.2686
Error	16	1469.840	91.865	
Total	24	4805.460	925.77	

Lsd(0.05)= 12.85; Lsd(0.01)= 17.71

Appendix 19

Data on the effect of different numbers of applications of mevinphos as a stem spray on *C.thysanura* eggs on Boronia plants at Copping,1987-88.(Mean results of 70 terminal shoots per treatment).

No.of treatment applications	Mean no.of eggs/terminal shoot								
	24hrs Pre-treatment counts	Post treatment counts (months)							
		Jan.	Feb.	Mar.	April	May	June	July	Aug.
2 sprays	3.69a	1.74a	2.26a	8.90a	10.59a	8.36a	8.39a	12.60a	28.74a
3 sprays	5.83a	2.74a	6.94ab	8.47b	7.17a	1.99b	3.81a	3.13b	9.97b
Control (Not sprayed)	4.03a	9.61b	8.86b	13.96ab	11.03a	12.29a	7.37a	10.67a	21.33c

Lsd(0.05)=5.46; Lsd(0.01)=7.66

Means within columns followed by the same letter are not significantly different,P>0.05,Duncan's multiple range test .

Appendix 20

Data on the effect of monocrotophos used as a foliage spray on *C.thysanura* eggs on boronia plants at Copping,1987-88.(Mean of 70 terminal shoots per treatment).

No.of treatments applications	Mean number of eggs/terminal shoot								
	24hrs Pre-treatment counts	Post treatment counts (months)							
		Jan.	Feb.	Mar.	April	May	June	July	Aug.
2 sprays	2.26a	1.01a	2.54a	8.04a	11.87a	9.36a	9.37a	14.23a	29.89a
3 sprays	3.66a	2.14a	2.86a	5.47a	4.59b	1.98b	1.21b	2.77b	4.60b
Control (Not sprayed)	3.30a	7.86b	10.51b	10.40a	12.03a	11.71a	14.83c	12.10a	22.61c

Lsd(0.05)=5.13; Lsd(0.01)=7.19

Means within columns followed by the same letter are not significantly different,P>0.05 Duncan's multiple range test.

Appendix 21

Data on the effect of different numbers of applications of mevinphos as a stem spray on *C.thysanura* on boronia plants at Copping,1987-88.(Mean of 70 terminal shoots per treatment).

No.of treatment applications	Mean no.of nymphs/terminal shoot								
	24hrs.Pre-treatment counts	Post treatment counts (months)							
		Jan.	Feb.	Mar.	April	May	June	July	Aug.
2 sprays	8.03a	6.39a	5.10a	4.33a	6.60a	7.37a	10.61a	13.37a	15.03a
3 sprays	11.27b	2.67b	1.99b	8.46b	7.46a	2.94b	2.93b	2.91b	2.99b
Control (Not sprayed)	7.23a	8.31a	9.07c	16.97c	12.40b	13.23c	12.04a	16.84c	18.49c

Lsd(0.05)=2.81; Lsd(0.01)=3.94

Mean within column followed by the same letter are not significantly different,P>0.05 Duncan's multiple range test.

Appendix 22

Data on the effect of different numbers of applications of monocrotophos as a foliage spray on *C.thysanura* nymphs on boronia plants at Copping,1987-88.(Mean results of 70 terminal shoots per treatment).

No.of treatment applications	Mean no.of nymphs/terminal shoot								
	24hrs.Pre-treatment counts	Post treatment counts (months)							
		Jan.	Feb.	Mar.	April	May	June	July	Aug.
2 sprays	7.31a	4.41a	4.67a	5.76a	7.60a	8.39a	11.90a	13.86a	16.43a
3 sprays	9.11a	2.83a	2.27a	5.49a	5.17a	1.74b	1.50b	2.10b	3.34b
Control (Not sprayed)	7.19a	6.23a	15.63b	18.63b	12.92b	15.30c	15.27a	18.80c	20.10a

Lsd(0.05)=3.84; Lsd(0.01)=5.39

Means within column followed by the same letter are not significantly different,P>0.05,Duncan's multiple range test.

Appendix 23

Data on the effect of different numbers of applications of mevinphos as a stem spray on *C.thysanura* parasitoid population on the boronia plants at Copping,1987-88.(Mean of 70 terminal shoots per treatment).

No.of treatment applications	Mean no.of parasitoids/terminal shoot 24hrs.Pre-treatment counts	Post treatment counts (months) Jan.	Feb.	Mar.	April	May	June	July	Aug.
2 sprays	0.17a	0.19a	0.06a	0.06a	0.26a	0.17a	0.08a	0.34a	0.24a
3 sprays	0.17a	0.17a	0.02a	0.06a	0.30a	0.14a	0.07a	0.24a	0.30a
Control (Not sprayed)	0.20a	0.17a	0.06a	0.07a	0.34a	0.17a	0.05a	0.33a	0.20a

Lsd(0.05)=0.11; Lsd(0.01)=0.15 NS

Differences between treatments were not significant P>0.05

Appendix 24

Data on the effect of different numbers of applications of monocrotophos as a foliage spray on *C.thysanura* parasitoid population at Copping,1987-88.(Mean results of 70 terminal shoots per treatment).

No.of treatment applications	Mean no.of parasitoids/terminal shoot 24hrs.Pre-treatment counts	Post treatment counts (months) Jan.	Feb.	Mar.	April	May	June	July	Aug.
2 sprays	0.21a	0.29a	0a	0a	0.03a	0a	0.03a	0.06a	0.07a
3 sprays	0.21a	0.04b	0a	0a	0a	0a	0a	0.03a	0.04a
Control (Not sprayed)	0.14a	0.10b	0.04a	0.03a	0.26b	0.14b	0.04a	0.17b	0.19b

Lsd(0.05)=0.11; Lsd(0.01)=0.16

Means within columns followed by the same letter are not significantly different,P>0.05,Duncan's multiple range test.

Appendix 25

Data on the effect of different number of applications of mevinphos stem spray on the growth (new nodes per terminal shoot) of boronia plants at Copping,1987-88.(Mean results of 10 replicates per treatment).

No.of treatment applications	Mean no.of new nodes formed/terminal shoot) 24hrs.Pre-treatment counts	Post treatment counts Jan.	Feb.	Mar.	April	May	June	July	Aug.
2 sprays	0	3.60a	6.80a	8.70a	10.90a	11:00ab	11.10ab	11.10ab	11.20a
3 sprays	0	5.30a	6.80a	7.80a	10.30a	12.90b	13.30b	14.20b	16.20b
Control (Not sprayed)	0	3.80a	5.20a	6.40a	7.60a	8.00a	8.40a	9.10a	9.30a

Lsd(0.05)=4.80; Lsd(0.01)=6.58

Means within column followed by the same letter are not significantly different,P>0.05,Duncan's multiple range test.

Appendix 26

Data on the effect of different applications of monocrotophos foliage spray on the growth of boronia plants at Copping,1987-88.(Mean of 10 replicates/treatment).

No.of treatment applications	Mean no.of new nodes/terminal shoot 24hrs.Pre-treatment counts	Post treatment counts (months) Jan.	Feb.	Mar.	April	May	June	July	Aug.
2 sprays	0	3.60a	6.50a	7.70a	9.70a	10.80a	10.90a	10.90a	11.00a
3 sprays	0	5.40a	8.10a	8.60a	9.80a	11.70a	12.50a	14.50a	17.50b
Control (Not sprayed)	0	3.90a	5.40a	6.20a	6.90a	8.20a	8.70a	9.20a	10.00a

Lsd(0.05)=6.43; Lsd(0.01)=8.80

Means within column followed by the same letter are not significantly different,P>0.05,Duncan's multiple range test.

Appendix 27

Data on the effect of different numbers of applications of mevinphos as a stem spray on *C.thysanura* eggs on Boronia plants at Copping,1987-88.(Mean results of 70 terminal shoots per treatment).

No.of treatment applications	Mean no.of eggs/terminal shoot								
	24hrs Pre-treatment counts	Post treatment counts (months)							
		Jan.	Feb.	Mar.	April	May	June	July	Aug.
2 sprays	3.69a	1.74a	2.26a	8.90a	10.59a	8.36a	8.39a	12.60a	28.74a
3 sprays	5.83a	2.74a	6.94ab	8.47b	7.17a	1.99b	3.81a	3.13b	9.97b
Control (Not sprayed)	4.03a	9.61b	8.86b	13.96ab	11.03a	12.29a	7.37a	10.67a	21.33c

Lsd(0.05)=5.46; Lsd(0.01)=7.66

Means within columns followed by the same letter are not significantly different,P>0.05,Duncan's multiple range test .

Appendix 28

Data on the effect of monocrotophos used as a foliage spray on *C.thysanura* eggs on boronia plants at Copping,1987-88.(Mean of 70 terminal shoots per treatment).

No.of treatments applications	Mean number of eggs/terminal shoot								
	24hrs Pre-treatment counts	Post treatment counts (months)							
		Jan.	Feb.	Mar.	April	May	June	July	Aug.
2 sprays	2.26a	1.01a	2.54a	8.04a	11.87a	9.36a	9.37a	14.23a	29.89a
3 sprays	3.66a	2.14a	2.86a	5.47a	4.59b	1.98b	1.21b	2.77b	4.60b
Control (Not sprayed)	3.30a	7.86b	10.51b	10.40a	12.03a	11.71a	14.83c	12.10a	22.61c

Lsd(0.05)=5.13; Lsd(0.01)=7.19

Means within columns followed by the same letter are not significantly different,P>0.05 Duncan's multiple range test.

Appendix 29

Data on the effect of different numbers of applications of mevinphos as a stem spray on *C.thysanura* on boronia plants at Copping,1987-88.(Mean of 70 terminal shoots per treatment).

No.of treatment applications	24hrs.Pre-treatment counts	Mean no.of nymphs/terminal shoot Post treatment counts (months)							
		Jan.	Feb.	Mar.	April	May	June	July	Aug.
2 sprays	8.03a	6.39a	5.10a	4.33a	6.60a	7.37a	10.61a	13.37a	15.03a
3 sprays	11.27b	2.67b	1.99b	8.46b	7.46a	2.94b	2.93b	2.91b	2.99b
Control (Not sprayed)	7.23a	8.31a	9.07c	16.97c	12.40b	13.23c	12.04a	16.84c	18.49c

Lsd(0.05)=2.81; Lsd(0.01)=3.94

Mean within column followed by the same letter are not significantly different,P>0.05 Duncan's multiple range test.

Appendix 30

Data on the effect of different numbers of applications of monocrotophos as a foliage spray on *C.thysanura* nymphs on boronia plants at Copping,1987-88.(Mean results of 70 terminal shoots per treatment).

No.of treatment applications	Mean no.of nymphs/terminal shoot 24hrs.Pre-treatment counts	Post treatment counts (months)							
		Jan.	Feb.	Mar.	April	May	June	July	Aug.
2 sprays	7.31a	4.41a	4.67a	5.76a	7.60a	8.39a	11.90a	13.86a	16.43a
3 sprays	9.11a	2.83a	2.27a	5.49a	5.17a	1.74b	1.50b	2.10b	3.34b
Control (Not sprayed)	7.19a	6.23a	15.63b	18.63b	12.92b	15.30c	15.27a	18.80c	20.10a

Lsd(0.05)=3.84; Lsd(0.01)=5.39

Means within column followed by the same letter are not significantly different,P>0.05,Duncan's multiple range test.

Appendix 31

Data on the effect of different numbers of applications of mevinphos as a stem spray on *C.thysanura* parasitoid population on the boronia plants at Copping,1987-88.(Mean of 70 terminal shoots per treatment).

No.of treatment applications	Mean no.of parasitoids/terminal shoot 24hrs.Pre-treatment counts	Post treatment counts (months) Jan.	Feb.	Mar.	April	May	June	July	Aug.
2 sprays	0.17a	0.19a	0.06a	0.06a	0.26a	0.17a	0.08a	0.34a	0.24a
3 sprays	0.17a	0.17a	0.02a	0.06a	0.30a	0.14a	0.07a	0.24a	0.30a
Control (Not sprayed)	0.20a	0.17a	0.06a	0.07a	0.34a	0.17a	0.05a	0.33a	0.20a

Lsd(0.05)=0.11; Lsd(0.01)=0.15 NS

Differences between treatments were not significant P>0.05

Appendix 32

Data on the effect of different numbers of applications of monocrotophos as a foliage spray on *C.thysanura* parasitoid population at Copping,1987-88.(Mean results of 70 terminal shoots per treatment).

No.of treatment applications	Mean no.of parasitoids/terminal shoot 24hrs.Pre-treatment counts	Post treatment counts (months) Jan.	Feb.	Mar.	April	May	June	July	Aug.
2 sprays	0.21a	0.29a	0a	0a	0.03a	0a	0.03a	0.06a	0.07a
3 sprays	0.21a	0.04b	0a	0a	0a	0a	0a	0.03a	0.04a
Control (Not sprayed)	0.14a	0.10b	0.04a	0.03a	0.26b	0.14b	0.04a	0.17b	0.19b

Lsd(0.05)=0.11; Lsd(0.01)=0.16

Means within columns followed by the same letter are not significantly different,P>0.05,Duncan's multiple range test.

Appendix 33

Data on the effect of different number of applications of mevinphos stem spray on the growth (new nodes per terminal shoot) of boronia plants at Copping,1987-88.(Mean results of 10 replicates per treatment).

No.of treatment applications	Mean no.of new nodes formed/terminal shoot) 24hrs.Pre-treatment counts	Post treatment counts Jan.	Feb.	Mar.	April	May	June	July	Aug.
2 sprays	0a	3.60a	6.80a	8.70a	10.90a	11.00ab	11.10ab	11.10ab	11.20a
3 sprays	0a	5.30a	6.80a	7.80a	10.30a	12.90b	13.30b	14.20b	16.20b
Control (Not sprayed)	0a	3.80a	5.20a	6.40a	7.60a	8.00a	8.40a	9.10a	9.30a

Lsd(0.05)=4.80; Lsd(0.01)=6.58

Means within column followed by the same letter are not significantly different,P>0.05,Duncan's multiple range test.

Appendix 34

Data on the effect of different applications of monocrotophos foliage spray on the growth of boronia plants at Copping,1987-88.(Mean of 10 replicates/treatment).

No.of treatment applications	Mean no.of new nodes/terminal shoot 24hrs.Pre-treatment counts	Post treatment counts (months) Jan.	Feb.	Mar.	April	May	June	July	Aug.
2 sprays	0a	3.60a	6.50a	7.70a	9.70a	10.80a	10.90a	10.90a	11.00a
3 sprays	0a	5.40a	8.10a	8.60a	9.80a	11.70a	12.50a	14.50a	17.50b
Control (Not sprayed)	0a	3.90a	5.40a	6.20a	6.90a	8.20a	8.70a	9.20a	10.00a

Lsd(0.05)=6.43; Lsd(0.01)=8.80

Means within column followed by the same letter are not significantly different,P>0.05,Duncan's multiple range test.

Appendix 35

Data of the effect of mevinphos stem spray and monocrotophos foliage spray on *C.thysanura* eggs in alarge scale trial at Copping.

Treatments	Mean no.of eggs per terminal shoot									
	24hrs.Pre-treatment counts	Post treatment counts (months)								
		Jan.	Feb.	Mar.	April.	May	2nd June	30th June	July	Aug.
Mevinphos stem spray	3.83a	0.74a	4.80a	6.47a	6.17ab	1.37a	1.81a	2.39ab	3.34a	9.11a
Monocrotphos foliage spray	1.66a	0.41a	0.79a	2.87a	2.47a	0.84a	0.50a	0.60a	1.77a	13.60a
Control (Not sprayed)	1.30a	6.19b	18.51b	18.40b	10.03b	10.53b	10.26b	6.66b	18.10b	30.90b

Lsd(0.05)=4.86; Lsd(0.01)=6.81

Means within column followed by the same letter are not significantly different,P>0.05,Duncan's multiple range test.

Appendix 36

Data on the effect of mevinphos stem spray and monocrotophos foliage spray on *C.thysanura* eggs on boronia plants at Huonville,1988-89.

Treatments	Mean no.of eggs/terminal shoot							
	24hrs.Pre-treatment counts	Post treatment counts (months)						
		Jan.	Feb.	Mar.	April	May	June	July
Mevinphos stem spray	65.71a	7.21a	15.89a	50.93a	12.76a	4.23a	0.46a	0a
Monocrotophos foliage spray	64.79a	5.17a	11.73a	42.24b	7.86a	3.29a	0.06a	0.04a
Control (Not sprayed)	60.24a	52.11b	50.69b	52.59a	20.54b	18.81b	4.89a	1.04a

Lsd(0.05)=7.55; Lsd(0.01)=10.58

Means wthin column followed by the same letter are not significantly different,P>0.05,Duncan's multiple range test.

Appendix 37

Data on the the effect of mevinphos stem spray and monocrotophos foliage spray on *C.thysanura* nymphs on boronia plant at Copping in the large scale trials.

Treatments	Mean no.of nymphs/terminal shoot									
	24hrs.Pre-treatment counts	Post treatment counts (months)								
		Jan.	Feb.	Mar.	April	May	2nd June	30th June	July	Aug.
Mevinphos stem spray	8.53a	1.57a	1.70a	3.99a	3.46a	2.94a	2.19a	1.99a	2.04a	3.53a
Monocrotophos foliage spray	7.54a	0.83a	0.27a	3.49a	3.46a	1.46a	1.07a	1.17a	1.54a	2.20a
Control (Not sprayed)	5.19a	4.23a	14.49b	17.06b	11.64b	14.01b	13.27b	16.66b	17.63b	17.20b

Lsd(0.05)=4.80; Lsd(0.01)=6.74

Means followed by the same letter are not significantly different,P>0.05,Duncan's multiple range test.

Appendix 38

Data on the effect of mevinphos stem spray and monocrotophos foliage spray on C.thysanura nymphs on boronia plants at Huonville.

Treatments	Mean no.of nymphs/terminal shoot							
	24hrs.Pre-treatment counts	Post treatment counts (months)						
		Jan.	Feb.	Mar.	April	May	June	July
Mevinphos stem spray	42.68a	4.84a	1.97a	9.11a	20.33a	2.44a	0.37a	0.40a
Monocrotophos foliage spray	42.67a	4.51a	0.73a	7.21a	19.13a	1.50a	0.14a	0.16a
Control (Not sprayed)	42.64a	35.17b	33.30b	41.99b	31.43b	34.63b	9.47b	1.47a

Lsd(0.05)=7.63; Lsd(0.01)=10.70

Means within column followed by the same letter are not significantly different,P>0.05,Duncan's multiple range test.

Appendix 39

Data on the effect on the application of mevinphos stem spray and monocrotophos foliage spray on *C.thysanura* parasitoid population at Copping,1987-88.

Treatments	Mean no.of parasitoids/terminal shoot									
	24hrs.Pre-treatment counts	Post treatment counts (months)								
		Jan.	Feb.	Mar.	April	May	2nd June	30th June	July	Aug.
Mevinphos stem spray	0.09a	0.08a	0.01a	0.06a	0.18a	0.07a	0.09a	0.01a	0.21a	0.27a
Monocrotophos foliage spray	0.06a	0.01a	0a	0a	0.01b	0.01a	0a	0a	0b	0.03b
Control (Not sprayed)	0.04a	0.07a	0.03a	0.09a	0.16a	0.09a	0.07a	0.06a	0.23a	0.29a

Lsd(0.05)=0.12; Lsd(0.01)=0.16

Means within column followed by the same letter are not significantly different,Duncan's multiple range test.

Appendix 40

Data on the effect of application of mevinphos stem spray and monocrotophos foliage spray on *C.thysanura* parasitoid population at Huonville,1988-89.

Treatments	Mean no.of parasitoids/terminal shoot							
	24hrs.Pre-treatment counts	Post treatment counts (months)						
		Jan.	Feb.	Mar.	April	May	June	July
Mevinphos stem spray	0.29a	0.10ab	0.03a	0.06a	0.77a	0.13a	0.00a	0.03a
Monocrotophos foliage spray	0.33a	0.01a	0.00a	0.01a	0.11b	0.06a	0.00a	0.00a
Control (Not sprayed)	0.30a	0.16b	0.03a	0.09a	0.67a	0.16a	0.00a	0.03a

Lsd(0.05)=0.14; Lsd(0.01)=0.19

Means within column followed by the same letter are not significantly different,P>0.05,Duncan's multiple range test.

Appendix 41

Data on the effect of mevinphos stem spray and monocrotophos foliage spray on the growth (new nodes per terminal shoot) of boronia plants at Copping,1987-88.(Mean of 10 replicates per treatment).

Treatments	Mean no.of new nodes formed/terminal shoot								
	Post treatment counts (months)								
	Dec.	Jan.	Feb.	Mar.	April	May	2nd June	30th June	July	Aug.
Mevinphos stem spray	0a	4.40a	7.60a	10.10ab	12.50a	13.40a	14.50a	15.00a	15.50a	16.00a
Monocrotophos foliage spray	0a	4.50a	8.00a	10.60a	13.00a	13.80a	15.30a	15.50a	16.30a	16.90a
Control (Not sprayed)	0a	3.90a	5.60a	6.70b	7.40b	8.00b	8.40b	9.20b	9.30b	9.70b

Lsd(0.05)=3.43; Lsd(0.01)=4.71

Means within column followed by the same letter are not significantly different,P>0.05,Duncan's multiple range test.

Appendix 42

Data on the effect of mevinphos stem spray and monocrotophos foliage spray on the growth of boronia plants at Huonville,1988-89.(Mean of 10 replicates per treatment).

Treatments	Mean no.of new nodes formed per terminal shoot							
	Post treatment counts (months)							
	Dec.	Jan.	Feb.	Mar.	April	May	June	July
Mevinphos stem spray	0a	4.90a	9.20a	12.90a	15.90a	17.50a	17.90a	19.10a
Monocrotophos foliage spray	0a	5.30a	9.50a	13.20a	16.50a	17.90a	18.10a	19.80a
Control (Not sprayed)	0a	4.20a	5.10b	6.30b	6.70b	7.50b	7.80b	7.00b

Lsd(0.05)=3.22; Lsd(0.01)=4.42

Means within column followed by the same letter are not significantly different,P>0.05,Duncan's multiple range test.