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PEST MANAGEMENT OF

THE NEW ZEALAND FLOWER THRIPS

THRIPS OBSCURATUS (CRAWFORD) (THYSANOPTERA: THRIPIDAE)

ON STONEFRUIT IN CANTERBURY, NEW ZEALAND.

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Abstract of a thesis submitted in partial fulfilment of the requirements for the degree of Ph.D.

PEST MANAGEMENT OF THE NEW ZEALAND FLOWER THRIPS *THRIPS OBSCURATUS* (CRAWFORD) (THYSANOPTERA: THRIPIDAE) ON STONEFRUIT IN CANTERBURY, NEW ZEALAND.

by

D.A.J. TEULON

The New Zealand flower thrips (*Thrips obscuratus* (Crawford)) is an important pest of stonefruit during flowering and at harvest in New Zealand. The biology and control of this species formed the basis for this study.

A simple method for laboratory rearing is described that facilitated studies on the bionomics of *T. obscuratus*. Aspects of reproduction, fecundity, requirements for oviposition and development, development rates, temperature thresholds, thermal constants, and lifespan are detailed.

T. obscuratus has been reported from at least 223 endemic and introduced plant species. Larvae were taken from 49 species around Canterbury. Adults were usually found on flowers but were also common on leaves and fruits. All larvae were on flowers except for two records from the fruit of stonefruit.

The number and species of thrips infesting sprayed and unsprayed stonefruit flowers and fruit were determined. Adults and larvae were almost all *T. obscuratus* and adults were mostly female.

Adults and larvae of thrips were found in stonefruit flowers from pink to shuck fall. Adults were found in similar numbers throughout flower development. Larvae were almost entirely absent at pink; numbers were small at full bloom and peaked at or just after petal fall.

Thrips adults, eggs and larvae were all common on peaches, nectarines and apricots. Thrips were most numerous on ripe fruit, although they were found on fruit for the local market up to three weeks before harvest. Thrips numbers were highest on stonefruit varieties ripening during December and January and lowest on varieties ripening during February, March and April, and were higher on peaches than apricots and nectarines.

Sources of *T. obscuratus* infestations were probably from flowers in the vicinity of the orchard.

Pupation sites for *T. obscuratus* were established as including the soil and litter beneath a flowering cabbage tree (*Cordyline australis*).

Female *T. obscuratus* were parasitised and sterilised by a nematode thought to be *Howardula aptini.*

Flying thrips were sampled inside and outside stonefruit blocks from September 1984 to August 1987. Several species including *T. obscuratus, Thrips tabaci, Limothrips cerealium* and *Haplothrips niger* were common. A broad pattern of the seasonal abundance of *T. obscuratus* was apparent from water trap samples. Thrips numbers were lowest in winter and low in spring, but increased gradually during summer. Numbers peaked in midsummer but declined suddenly in mid to late January. Numbers remained moderate to low throughout late summer and autumn. Seasonal abundance could be largely explained by the interrelationship of temperature, soil moisture and availability of host plants. Flight take-off thresholds of 15^{o}C were established from weekly water trap samples for both male and female *T. obscuratus* adults.

Both adults and larvae of *T. obscuratus* were found on hosts throughout the year, but were most common in early summer. There was no reproductive diapause for *T. obscuratus* females collected from the field in winter.

In field experiments *T. obscuratus* males and females showed a preference for white without U.V., and to a lesser extent yellow, compared to green, blue, black and red. Traps baited with ethyl nicotinate caught significantly more *T. obscuratus* males and females than traps baited with anisaldehyde, benzaldehyde, peach juice, peach fruit and unbaited traps.

An insecticide trial investigated the protection of nectarine flowers from thrips infestation and damage,using the insecticides fluvalinate or phosalone (low toxicity to bees) applied at full bloom as supplements to the current recommended spray programme. Thrips numbers were reduced, and export packout (based on russet only) was 10% higher for trees treated at full bloom than for those treated only with the recommended spray programme.

Several varieties of ripe stonefruit picked at maturity for the local market and which had received only periodic applications of carbaryl were infested with adults, eggs and larvae.

The application of low rates of fluvalinate for preharvest control of thrips on peach fruit was investigated. Peaches were sampled for thrips at local market maturity ('Redhaven') and export market maturity ('Flamecrest'). Low rates of fluvalinate (20% to 5% of field rates) reduced thrips infestation on both varieties. On 'Flamecrest' one application of fluvalinate at 10% field rate, 15 days before harvest, was more effective at reducing thrips infestation than the current recommended spray programme.

The management of *T. obscuratus* on stonefruit in Canterbury is reviewed in relation to previous research and knowledge gained from this study.

KEYWORDS: *Thrips obscuratus*, Thysanoptera, Thripidae, thrips, rearing, bionomics, biology, ecology, pest, pest management, stonefruit, nectarine, peach, flower, fruit, New Zealand.

PLATE 1. NEW ZEALAND FLOWER THRIPS (FEMALE x80 APPROX.).

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CHAPTER I

GENERAL INTRODUCTION

Historically New Zealand has relied heavily on agricultural products to earn overseas revenue. With the contraction of these markets, as well as New Zealand's gradual exclusion from the European Economic Community, there has been a strong incentive to diversify into other areas such as horticulture. The growth of the kiwifruit export sector during the 1970s and 1980s is clear evidence of this.

The expansion of new horticultural crops into the export market has led to a change in the economic status of many insect pests, including some endemic to New Zealand. Insect damage to and contamination of export produce has often increased pest status, due to reduced tolerance levels in export markets. With the recent invasion of exotic biota into New Zealand, most endemic insects have retreated with the dwindling endemic flora. There are a few exceptions, however; some of these have become notable pests, such as the grass grub (*Costelytra zealandica* (White)) a pest of pasture, and the native leafrollers (*Ctenopseustis obliquana* (Walker), *Planotortrix excessana* (Walker)) that are pests of horticultural crops.

Another endemic species that has become recognised as causing economic injury to several export crops is the New Zealand flower thrips (*Thrips obscuratus* (Crawford)). The biology and control of this species forms the basis for this thesis.

Originally an inhabitant of endemic flowering plants, *T. obscuratus* soon colonised a considerable number of plants introduced with European settlement of New Zealand. It is now considered the most ubiquitous and widespread of the New Zealand thrips (Walker 1985). First discovered as a pest in grape flowers (Crawford 1941), *T. obscuratus* is associated with distortion of the young growth of passionfruit (May 1963) and russetting of nectarine fruit (Anon. 1979, McLaren 1981). Recently *T. obscuratus* has become an important problem as a contaminant of export horticultural produce including kiwifruit, peaches, strawberries (Mound and Walker 1982) and cut flowers (Chapman *et al.* 1985).

As an order, the Thysanoptera are the smallest of winged insects. They are characterised by the possession of protrusible bladders on the tips of the tarsi and asymmetric mouthparts in which only the left mandible is developed (Lewis 1973, Mound *et al.* 1980). Because of their size, thrips are frequently overlooked, and few entomologists have specialised in studying them (Lewis 1973). Thrips have received progressively more attention as they have become recognised as economically important pests in agriculture and horticulture and as natural enemies of other crop pests (Lewis 1973, Bournier 1983), as vectors of plant viruses and bacterial diseases (Anathakrishnan 1980), as agents of weed control (Simmonds 1933) and as possible pollinators (Ananthakrishnan *et al.* 1981). Presently there are over 4500 recognised species worldwide (Mound *et al.* 1980), although only a few hundred of these are recorded attacking cultivated plants (Lewis 1973).

The thysanopteran fauna of New Zealand has only recently been examined in any detail. Smith (1933) reported seeing thrips in New Zealand in about 1880 but it was not until later that any species were

identified (Muggeridge 1932). Initially most of these were introduced species (Wise 1977). The described thrips species in New Zealand increased slowly from 11 (Spiller 1951), to 22 (Spiller 1956), to 34 (Wise 1977) to the 120 species described by Mound and Walker (1982, 1986, 1987).

Only a small proportion of the known thrips species in New Zealand are pests of any significance, and of these all but *T. obscuratus* have been introduced on imported plant material over the past 150 years or blown across the Tasman Sea from Australia. Several other species are potentially important, as they are sometimes found in damaging numbers on plants in New Zealand or are important pests overseas that for some reason have not yet proved damaging in New Zealand. Of these only *Thrips phormiicola* is endemic to New Zealand. At least three species of thrips are considered to be important as predators of small soft-bodied insects and/or mites in New Zealand.

Observations on the biology of thrips in New Zealand have been limited to research on a few introduced species (Yates 1952, Doull 1956b, Helson 1973, Zondag 1977) and general references in applied entomological texbooks (e.g., Cottier 1956, Butcher 1984, Chapman 1984). Other references simply list thrips species found in sampling (e.g., Cottier 1931, Doull 1956a) or discuss thrips in relation to plant protection (e.g., Cottier 1938, Atkinson *et al.* 1949, Cumber 1954). There has been little work on the biology or life histories of native thrips (Mound and Walker 1982). Recently research has been carried out on *T. obscuratus* in relation to control on stonefruit although little of this work has been published (Anon. 1979, 1980, McLaren 1980-1987).

In the last five years the stonefruit industry in New Zealand has expanded and become increasingly export-orientated. Integrated pest management (I.P.M.) is necessary to fulfil the requirements of export markets, for crops that are free from damage and contamination of pests with minimum pesticide residues. These requirements may restrict the control strategies that are needed for the range of pest insects and diseases of stonefruit.

Direct damage by *T. obscuratus* to nectarines in the form of russet (see Plate 2), and contamination of ripe nectarines and peaches (see Plate 3) makes this insect a particularly important pest of export stonefruit crops. In commercial orchards, up to thirty per cent of fruit can be rejected for export because of russetted fruit, considered to be primarily caused by thrips (McLaren 1982). Failure to treat trees with insecticides during flowering can render all the fruit unmarketable (Kemp 1959). High levels of thrips contamination on export fruit may jeopardise the accessibility of markets, and fumigation adds costs to the production process. It has been claimed that ninety per cent of export stonefruit entering Australia by air from New Zealand are fumigated for insects including thrips, mites and leafrollers (Johnston 1985). Bollard (1981) mentioned the phytosanitary problems of thrips on stonefruit exports as having 'a large actual or potential effect on production or marketing'.

Among other 'key' insect pests which dominate the control programme of stonefruit are several species of leafroller including the lightbrown apple moth (*Epiphyas postvittana* (Walker)), and, where it occurs, the Oriental fruit moth (*Cydia molesta* (Busck)) (Dale 1976, Tomkins 1985). The European red mite (*Panonychus ulmi* (Koch)) and San José scale (*Quadraspidiotus perniciosus* (Comstock)) can also be important pests of stonefruit (Charles 1984, Penman 1984). Seasonal pests include the green peach aphid (*Mysus persicae* (Sulzer) and the grass grub (*Costelytra zealandica*) (Butcher 1984, Cruickshank 1987).

PLATE 2. THRIPS DAMAGE TO NECTARINE FRUIT IN THE FORM OF RUSSET.

PLATE 3. THRIPS INFESTING 'REDHAVEN' PEACHES.

Pests that occur sporadically include the bronze beetle (*Eucolapsis brunnea* (F.)) and the European earwig (*Forficula auricularia* L.) (Kemp 1971, Tomkins 1985).

Many of the stonefruit pests listed above are common on other deciduous crops in New Zealand (e.g., leafrollers and mites on apple) or are found overseas (e.g., the Oriental fruit moth). Thus much information on the biology and ecology of these species is already known. This is not the case for *T. obscuratus*. Relatively little is known of this insect's biology and ecology, because until very recently it had not been reported from overseas and it has not been considered a serious pest of other crops in New Zealand. Control strategies for *T. obscuratus* on peaches and nectarines have therefore been developed with a limited ecological understanding, and chemical applications are almost the only means of control used.

The overall objective of the work in this thesis is to investigate the biology and ecology of *T. obscuratus* so that rational decisions can be made concerning the management of this species especially in relation to stonefruit.

Specific aims within this objective include:

1. an examination of the life history of *T. obscuratus* under controlled conditions in the laboratory to confirm field observations;

2. an investigation of the biology and ecology of *T. obscuratus* under field conditions to establish sources and degree of infestation, timing of infestation in relation to time of year and phenology of host plants and the influence of natural enemies; and

3. an investigation of the effectiveness of presently recommended control strategies for *T. obscuratus* on peaches and nectarines, and alternative control methods for pest management.

CHAPTER II

LITERATURE REVIEW

1 INTRODUCTION

This chapter contains a selected review of the literature on thrips, especially the New Zealand flower thrips (*Thrips obscuratus*), and their economic significance in relation to stonefruit. A brief summary of peach and nectarine cultivation is also included. This review serves as a knowledge base for further investigations of the biology and ecology of *T. obscuratus*. Extended reviews of the biology, ecology and economic importance of thrips in general can be found in Lewis (1973) and Bournier (1983).

2 TAXONOMY

The order Thysanoptera comprises 2 suborders: the Terebrantia and the Tubilifera. There are 2000 described species of the Terebrantia which are particularly common in flowers. The 2500 described species of the Tubilifera are more common on dead wood, in leaf litter or in leaf galls. In New Zealand 52 species in 26 genera are placed in the Terebrantia and 68 species in 29 genera in the Tubilifera (Mound and Walker 1986, 1987). Mound and Walker (1982, 1986) deal comprehensively with the systematics of both suborders including notes on distribution, habitat, host plants and life history for each species. They also discuss pests, phylogeny and morphology.

Within the Terebrantia, some 1500 species are placed in the family Thripidae 47 of which are recorded from New Zealand. Two subfamilies are recognised: the Panchaetothripinae, which are more primitive and appear to feed on leaves, and the Thripinae, many of which inhabit flowers. Within the Thripinae the flower-inhabiting subtribe Thripina contains what are considered to be the most advanced thrips species. At least twenty-five species of Thripina are recorded from New Zealand including 12 species in the genus *Thrips*. The genus *Thrips* is the largest genus of flower-feeding Thysanoptera and includes 4 species that are endemic to New Zealand.

T. obscuratus was first descibed by Crawford (1941) from grape flowers collected in Henderson, Auckland, New Zealand, under the name *Isoneurothrips obscuratus*. Other names that this species has appeared under in the literature include: *Isothrips (Isoneurothrips) obscuratus* (Crawford) May (1963), *Thrips (Isothrips) obscuratus* (Crawford) Sakimura (1967). For the thrips species mentioned in this thesis the names used by Jacot-Guillamod (1970-1978) and Mound and Walker (1982, 1986) are accepted. In Appendix 1 thrips are grouped with their authorities according to their taxonomic status after Jacot-Guillarmod (1970-1978) and Mound *et al.* (1980).

3 BIOLOGY AND ECOLOGY OF THRIPS

3.1 MORPHOLOGY

General descriptions of thrips structure are given by Lewis (1973), Mound and Walker (1982, 1986) and Bournier (1983). Detailed descriptions of the morphology of *T. obscuratus* are found in Crawford (1941), Mound (1978) and Mound and Walker (1982). Unfortunately current descriptions of immature stages are not adequate to distinguish between species or larval instars.

3.2 DISTRIBUTION

The great majority of thrips, including almost all species of economic importance, belong to the families Thripidae and Phlaeothripidae, which are distributed throughout the world (Lewis 1973). *T. obscuratus* is considered to be endemic to New Zealand (Spiller 1951, Mound 1978, Mound and Walker 1982). It has been recorded from many parts of New Zealand and is the most ubiquitous and widespread of any New Zealand thrips. It is particularly common in lowlands, but also abundant in the alpine zone (Mound and Walker 1982).

A population of this species is probably present in Queensland, Australia. Adults identified as *T. obscuratus* were intercepted in Christchurch, New Zealand, in December 1985 on rock melons air-freighted from Brisbane. Normal quarantine procedures would preclude the likelihood of infestation after arrival in New Zealand (B Stephenson pers. comm.). Presumably *T. obscuratus* was carried to Australia from New Zealand on infested plant material.

3.3 HOSTS

THYSANOPTERA

The pleisiotypic habitat of thysanopterans is presumed to have been leaf-litter where they fed on fungal hyphae and pupated in the soil. From this habitat the group appears to have moved into flowers (Mound *et al.* 1980).

Thrips species that inhabit flowers include some members of the Tubiliferan family: Phlaeothripidae (mostly *Haplothrips* spp., Lewis 1973), Aeolothripidae (Mound and Walker 1982), *Heterothrips* spp. and some members of the Thripini (Mound *et al.* 1980).

Many thrips are positively thigmotaxic (Lewis 1973) and the small spaces within flowers provide a suitable microclimate for ovipostion and larval development. Flowers also provide an accessible source of soluble protein in the form of pollen (Mound *et al.* 1980) and nectar provides a valuable source of carbohydrate (Kevan and Baker 1984). Other floral tissues may also be important sources of nutrition for thrips (Murai and Ishii 1982, Kirk 1985). Temperatures within flowers may be several degrees above ambient and increase the speed of insect development (Kevan and Baker 1984).

The degree of host specificity varies among flower thrips. Some species are found on a wide range of flowers and are known to feed on several host plants, whereas others have a more restricted host plant

range (Kirk 1985). Specificity may be influenced by the size of crevices within the flower (Lewis 1973) and pollen type (Kirk 1985).

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T. obscuratus is highly polyphagous, being collected from a wide range of introduced and endemic plants (Spiller 1951, 1956, Norton 1984), not only on flowers but also on leaves, leaf litter, birds' nests and moss (Mound and Walker 1982). As *T. obscuratus* has accepted many introduced plants as hosts, it now shows a remarkable dominance in the flower-living niche throughout New Zealand (Mound and Walker 1982) and it may have become increasingly common since the introduction of exotic plants (Mound 1978).

Host plant species lists for *T. obscuratus* are found in Spiller (1951, 1956), which were updated (but by only two more records) by Spiller and Wise (1982). Some reports have described host plants for *T. obscuratus* from particular environments (e.g., fodder crops - Cumber and Eyles 1961, lowland forest - Norton 1984). Other records of host plants are scattered in the literature. Norton (1984) reported that *T. obscuratus* was known from native plants in 18 of the 112 spermatophyte families in New Zealand.

The breeding hosts of *T. obscuratus* are less clear, as the published literature reports mainly hosts on which only adults have been found. Mound and Walker (1982) listed *Prunus* sp. (sour cherry) and 2 spp. of *Phormium* as breeding hosts. Eggs and larvae were reported from apricot (*Prunus armeniaca*) (McLaren 1986), nectarine and peach (*Prunus persica*) (McLaren 1981, 1982, 1983b) and eggs on rose (*Rosa* sp.) (McLaren 1982). However there is no suitable key to identify *T. obscuratus* larvae and no mention was made of rearing larvae to adults for identification. Indeed, the first records of laboratory rearing of *T. obscuratus* are found in this thesis. Identification of larval hosts is important, as it distinguishes host plant species where breeding takes place from plants on which transient adults may alight (Kirk 1987a).

3.4 FEEDING BEHAVIOUR

THYSANOPTERA

Thrips have varied diets reflecting their host preferences. Many species feed on the cell contents of the tissue of green plants (e.g., leaves, flowers, fruit and young shoots) as well as pollen, nectar and other exposed plant liquids, small arthropods and fungal hyphae and spores (Kirk 1984a). The Thysanoptera are the only insect group that suck the contents of pollen (Grinfel'd 1959, Kirk 1984a).

Thrips have unique asymmetrical mouthparts comprising a single mandibular stylet and paired maxillary stylets, protected and supported within a mouthcone projecting downwards from the ventral surface of the head (Chisholm and Lewis 1984).

The method of feeding in the Thysanoptera is incompletely understood (Lewis 1973). Unlike most piercing/sucking insects, thrips do not feed from vascular tissues. Rather, thrips are known to pierce or rupture plant cells with their single mandible and drain or lap up cell contents with the maxillary stylets. Some species also 'drink' nectar from flowers (Lewis 1973).

The best description of thrips feeding is given by Heming (1978) for the larvae of *Haplothrips verbasci*. When a larva is ready to feed, it grasps the surface of the leaf with its pretarsi, sinks down between its front legs, lifts its head, and places the tip of its mouthcone against the surface. It then shortens its mouthcone and punches a hole in the epidermis by rapidly and repeatedly protracting and retracting its left mandibular stylet. The thrips then inserts its two maxillary stylets as a unit into the wound with a series of rapid thrusts and withdrawals, salivating continuously while doing so. When a food source in the epidermis or mesophyll is found, probing and salivation stop and cibarial pumping begins. Cytoplasm is sucked into the opening at the tip of the protracted stylets, up the food canal between them and into the cibarium. Mound *et al.* (1980) coined the term 'punch and suck' for the feeding action of thrips described by Heming.

The mechanical action of the mouthparts piercing plant tissue is not considered to be particularly destructive in itself. The broad area of cells around the puncture are emptied of their contents and take on a whitish appearance (Bournier 1970). Tne saliva which breaks down plant tissue also diffuses through the cell walls and destroys neighbouring cells (Kloft and Ehrhardt 1959). The cytoplasm of dead cells dehydrates and these cells also take on a whitish appearance which gradually turn brownish and are visible as necrotic patches (Bournier 1983). Other detailed descriptions of thrips feeding are found in Chisholm and Lewis (1984) for feeding through artificial membranes, and Grinfel'd (1959) and Kirk (1984) for pollen.

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T. obscuratus has been observed feeding in the flowers of several native trees (Norton 1984). On horopito (*Pseudowintera axillaris* (J.R. *et* G. Forst.) Dandy) thrips followed the circular gap between the whorls of stamens and consumed pollen in the crevices between the stamens. On ngaio (*Myoporum laetum* Forst. f.) *T. obscuratus* fed on pollen from an anther, moved to the base of the ovary to consume the nectar and then crawled up the style for the exudate of the stigma. On male flowers of the five-finger (*Pseudopanax arboreus* (Murray) Philipson), *T. obscuratus* did not feed on the pollen directly from the anthers. Instead the thrips remained on the central disc where the pollen, once shed, collected with the nectar. Pollen grains were grasped by, or adhered to, the thrips' front legs as it crawled through the food mixture. The thrips stood vertically at the base of the petals and clutched the pollen with its palps and front legs to draw one grain to its mouthparts. In other pollen-feeding thrips, Grinfel'd (1959) also found that pollen was manipulated to the mouth with the aid of the anterior legs, but Kirk (1984) found the use of the legs to be atypical.

Adults of both sexes of *T. obscuratus* have also been observed feeding on the nectar, petals and pollen of sour cherry flowers, while larvae were located feeding and sheltering in the bracts at the base of the flower cluster (McLaren unpubl.). In the laboratory Kirk (1987b) estimated the mean daily feeding rate for *T. obscuratus* on pollen of kiwifruit (*Actinidia chinensis* (Chevalier) Liang & Ferguson).

3.5 LIFE HISTORY

THYSANOPTERA

The phenology of flower thrips on their hosts have been described for a number of thrips species (Bailey 1938, Quayle 1938, Laughlin 1970, Kirk 1984b). Flower thrips invade their host as soon as they begin to flower and lay eggs if conditions are suitable. In the flower-inhabiting Terebrantia, eggs are laid singly in green plant tissues. In hosts with short-lived flowers, eggs may be laid in plant parts that are not lost with flower abscission (Kirk 1984b). The larvae hatch and feed in the flower, moulting once. Larval mortality may be high in hosts where flowers last for a short period (Laughlin 1970) unless they migrate from one flower to another to complete development (Kirk 1984b). In many hosts there is ample time for larval growth. Some Terebrantia pupate on the host plant (Mound and Walker 1982), but normally second instar drop to the ground (Evans 1932, Laughlin 1970) where they may pupate close to the surface or burrow up to 80 mm (three inches) in search of moisture (Evans 1932). There are two relatively inactive pupal stages known as the prepupa and pupa. At eclosion adults emerge from the soil and return to their original host if it is still flowering, or seek alternative flowering hosts. When the life cycle is not influenced by diapause, development from egg to adult is commonly about 10 to 30 days depending on thrips species and environmental conditions (Lewis 1973).

In many thrips populations, males are often rare or absent. Two forms of parthenogenetic reproduction found amoung thrips largely explain this imbalance in sex ratios. With arrhenotokous reproduction, unfertilised eggs give rise to males (haploid) and fertilised eggs to females (diploid). Thrips populations undergoing arrhenotoky commonly have sex ratios of four females to one male (Lewis 1973). With thelytokous reproduction males are unknown. Virgin females produce female offspring only (Lewis 1973).

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The life cycle of *T. obscuratus* is poorly understood but is probably similar to that of other flower-inhabiting Terebrantia. Oviposition sites for *T. obscuratus* have been reported in apricot leaves (McLaren unpubl.), on the stalk of cherry flowers, in the midrib of young nectarine leaves, the base of rose petals (McLaren 1982), the bud stalks of *Phormium* (Mound and Walker 1982), the nectary of the nectarine flower (McLaren 1983b) and under the epidermis on the outside of the calyx of apricot flowers (McLaren 1986). Larvae have been recorded on apricot leaves (McLaren unpubl.), feeding deep inside the bracts around unopened *Phormium* flower heads (Mound and Walker 1982), feeding and sheltering in the bracts at the base of sour cherry flower clusters (McLaren unpubl.), in very protected positions close to the oviposition sites in nectarine flowers (McLaren 1983b) and on young fruit (McLaren 1981), and inside apricot flowers (McLaren 1986). On the skin of ripe peaches, larvae have also been found (McLaren 1986) that have hatched from eggs laid within the peach skin (McLaren pers. comm.).

Prepupae of *T. obscuratus* have been collected from the damp cellulose substrate of caged infested *Phormium* flower heads (Mound and Walker 1982), and pupae developed in the bracts at the base of

bagged sour cherry flower stalks (McLaren 1985). Both Mound and Walker (1982) and McLaren (1985) suggested that pupation took place in the ground.

In Central Otago, one generation (i.e., adult to adult) occurred on nectarine flowers between full bloom (September?) and late October-early November (McLaren 1981). On sour cherry 25 days elapsed from the time of oviposition at full bloom to adult emergence (McLaren 1983b, 1984).

Generally *T. obscuratus* females have been found to outnumber males (Penman *et al.* 1982, McLaren 1985), although adults have sometimes been collected in similar ratios (e.g., on roses, McLaren 1985 and *Phormium*, Mound and Walker 1982). In Central Otago in the 1982-83 and 1983-84 seasons, males did not appear on nectarine trees until late October and then remained in low numbers until late November (10-20% of the sample) (McLaren 1985). In the 1984-85 season males appeared in early October (McLaren 1986).

3.6 REQUIREMENTS FOR DEVELOPMENT

The total number of eggs laid by female thrips ranges from 30 to 300 depending on the species, the individual and the amount and quality of food available (Lewis 1973). The major factors that influence the rate of egg production are temperature and food. Oviposition may cease below a given threshold temperature and the frequency of egg laying increases with temperature (Andrewartha 1935, Rivnay 1935). Total egg production may not be adversely affected if lifespan increases proportionately at lower temperatures. Young females of *Thrips tabaci* and *Frankliniella tritici* lay more eggs in a given period than older ones (Watts 1936, Sakimura 1937), but females of *Thrips imaginis* and *Heliothrips haemorrhoidalis* lay steadily throughout their lifetime (Andrewartha 1935, Rivnay 1935).

The addition of pollen to diets of flower thrips has a marked effect on oviposition. Oviposition is much higher with pollen than with diets of other floral tissues, fruit and sugar solutions (Andrewartha 1935, Murai and Ishii 1982, Kirk 1985). Generalist flower thrips such as *Thrips fuscipennis* lay similar numbers of eggs with several species of pollen, whereas thrips showing more specific host requirements lay more eggs with their respective host pollens (Kirk 1985). Humidity may be an important influence on oviposition with some thrips. In dry atmospheres *Haplothrips subtilissimus* females laid fewer eggs than females in an almost saturated atmosphere (Putman 1942). Humidity is unlikely to be an important limitation for oviposition of flower thrips, as eggs are often laid in the protected positions of the flower where humidity would be relatively high.

Egg, larval and pupal development are influenced by temperature. Development ceases at a lower temperature threshold, increases with increasing temperature and may be inhibited by higher temperatures (Evans 1932, Rivnay 1935, Andrewartha 1936, Tanigoshi *et al.* 1980). Extreme temperatures may kill thrips. With flower thrips, type larval food is also important for development. Andrewartha and Kilpatrick (1951) claimed that development of the young stages of the apple thrips would not take place unless their diet included pollen. Pollen was also an important ingredient in the larval diet of *Frankliniella intosa* (Murai and Ishii 1982).

Humidity has been shown to be important in pupal development. A relative humidity of 75% was necessary for pupation in *Heliothrips haemorrhoidalis* (Rivnay 1935) and dry soils may be lethal to *Thrips*

imaginis pupae (Andrewartha 1934). Other stages are less affected by humidity, as eggs are embedded in plant tissues and larvae and adults can replace their losses through water taken with food.

Temperature is an important factor in determining adult lifespan. At lower temperatures thrips live longer than at higher temperatures (Andrewartha 1935, Rivnay 1935).

3.7 FLIGHT TAKE-OFF TEMPERATURE THRESHOLDS AND DIURNAL ACTIVITY

THYSANOPTERA

Thrips are among the weakest flying insects, yet they are commonly found at heights of 600 m and are known to travel long distances (Lewis 1973). Immediately before takeoff, thrips stand in an elevated position poised with wings held backward at a steep angle and abdomen curved upwards to assist spreading the wings. They launch themselves upwards with a kick of the legs (Lewis 1973). Once airborne, thrips have little directional control and are carried in the direction of the wind even in the lightest breezes (Lewis 1973). Their great dependence on wind for dispersal probably means that they are blown to within a few centimetres of an object before they can orientate for landing (Lewis 1973). Settling patterns are largely determined by local air currents formed when the wind encounters obstacles such as the edge of crops or sheltering hedges and trees (Lewis 1973).

Temperature is considered the most important environmental factor influencing thrips take-off in temperate regions (Lewis 1973). Threshold temperatures for take-off are usually distinctly defined and commonly range between 17-20^{o}C for populations living in temperate regions (Lewis 1973).

THE NEW ZEALAND FLOWER THRIPS

Suction trapping in Central Otago showed that there was a wide hourly and daily variation in the number of *T. obscuratus* adults caught. Adults were caught only when temperatures were between 15 and 30^{o}C (McLaren 1981). This was significant in terms of sampling, as thrips were absent on stonefruit trees between 3 p.m. and 11 a.m. during October and November (McLaren unpubl.). Contradictory results for flight take-off thresholds were obtained by McLaren (1985).. Twenty sticky traps, cleared daily throughout October and November for two seasons at the Clyde Research Centre, Central Otago, were compared with daily weather data. They showed that maximum numbers of thrips were trapped on calm days when the maximum temperature exceeded 19^{o}C. Numbers decreased with increasing windspeed. The flight take-off threshold for *T. obscuratus* is therefore likely to be between 15 and 19^{o}C.

3.8 SEASONALITY

THYSANOPTERA

Factors that influence population abundance in thrips include: the initial population size, immigration and emigration, weather, availability of hibernation and breeding sites, parasitism and predation (Lewis 1973). In suitable conditions the increase in population density over a season may be much greater for a species with several generations than one with few generations (Lewis 1973).

Annual cycles in the Thysanoptera fall into three categories. Firstly, continuous generations occur throughout the year with no diapause (e.g., *Frankliniella tritici*, Watts 1936), and the number of generations per year is determined by temperature. Secondly, adult bracypterous thrips overwinter in the soil having one or two generations per year (e.g., *Thrips angusticeps*, Franssen and Huismann 1958). Thirdly, larvae overwinter in the soil having one (e.g., *Kakothrips pisivorus*, as *K. robustus*, Williams 1915), or two (e.g., *Haplothrips leucanthemi*, Loan and Holdaway 1955) generations per year.

Some winged thrips species fly for only a few weeks each year, with days when sudden mass flights occur (Lewis 1973). These are usually species with temporary habitats. Many flower-inhabiting species have a more extended flight period throughout late spring and summer (Davidson and Andrewartha 1948, Lewis 1961).

THE NEW ZEALAND FLOWER THRIPS

Adults and larvae of *T. obscuratus* have been found throughout the year in flowers and on leaves of many plants (Mound and Walker 1982), so there appears to be no form of diapause over the winter months. Even in Central Otago, where flowering plants are scarce in winter, *T. obscuratus* females collected from *Verbascum thapsus* in May, June and July were active and showed no sign of diapause (McLaren 1985). If diapause is not present there are probably several generations of *T. obscuratus* per year. On the basis of several seasons of sticky board samples, Penman *et al.* (1982) in Canterbury and McLaren (1984) in Central Otago suggested that there were between six and eight generations per season.

Peak population numbers of *T. obscuratus* have been recorded in November from suction traps placed under a peach tree in Central Otago (McLaren 1981) and in pasture samples at Wakefield, Nelson (Martin 1983). Maximum trap catches of *T. obscuratus* in Cantebury coincided with the ripening of apricots in January (Penman *et al.* 1982).

3.9 NATURAL ENEMIES

Lewis (1973) and Bournier (1983) have reviewed the literature on natural enemies of thrips worldwide, while Mound and Walker (1982) have discussed this in relation to the small amount of information available for thrips' natural enemies in New Zealand.

PREDATORS

Thrips are prey to many general predators including anthrocorids, lygaeids and mirids, lacewings, coccinellids, dipterous larvae, mites and other thrips (Bournier 1983). Mound and Walker (1982) gave details of three New Zealand species of the Sphecid wasp *Spilomena*, which take *T. obscuratus* as prey and store them in abandoned *Anobium* beetle burrows. These three species were described by Vardy (1987), but only *Spilomena elegantula* Turner was identified as a predator of *T. obscuratus*. Vardy (1987) also questioned the identity of the beetle burrows. An Aeolothripid, *Desmidothrips walkerae* , has been collected in *Hebe* flowers in circumstances which suggested that it was preying on *T. obscuratus* (Mound and Walker 1982).

PATHOGENS

A summary of fungal infestation of thrips is found in Lewis (1973). The fungi attacking thrips are probably not specific to them, but are general and widespread entomogenous species. Mound and Walker (1982) reported a specimen of *T. obscuratus* infested by *Entomophthora* sp.

PARASITES

Although no thrips parasites are reported in New Zealand, several are known from overseas. These include internal egg and larval parasites from the Eulophidae, Trichogrammatidae and Mymaridae (Lewis 1973), and Chalchidoid ectoparasites (Bournier 1983). Lewis (1973) reported a few records of thrips infested with the nematode *Howardula aptini* (Sharga). This species has been recorded from Great Britain (Sharga 1932, Lysaght 1937), North America (Nickle and Wood 1964, Wilson and Cooley 1972) and India (Reddy *et al.* 1982). One or two gravid female nematodes occupy the abdominal and sometimes the thoracic cavity of the thrips, where they lay about 50 (10-110) eggs. The larval worms develop in the coelom of the host and eventually escape by boring through the wall of the midgut and passing out through the anus. After a short free-living stage, the infective vermiform females penetrate the cuticle of the thrips larva or pupa, where they swell into a sac-shape (Lewis 1973). Infected thrips may be found at any time of the year, but the number of eggs and larvae in each thrips is greatest in spring and summer (Lewis 1973). Peak parasitism rates of around 60 to 70 percent are found in summer (Sharga 1932, Nickle and Wood 1964, Reddy *et al.* 1982).

The nematodes do not affect the appearance or movement of their hosts, but cause their ovaries to degenerate, so that although the thrips are not killed the rate of increase of infected populations is retarded as egg production ceases (Lewis 1973).

4 ECONOMIC IMPORTANCE OF THRIPS

4.1 THRIPS AS BENEFICIAL INSECTS

THYSANOPTERA

A small proportion of the known thrips species are beneficial, including a few that prey on harmful thrips and other small arthropod pests and a few phytophagous species that have been exploited to control weeds (Lewis 1973, Bournier 1983). At least three species of thrips are considered to be important as predators in New Zealand: *Apterygothrips collyerae* (as *Xylaplothrips* nr. *fuliginosus*, Collyer 1976), *Aeolothrips fasciatus* (Cottier 1931) and *Haplothrips kurdjumovi* (Mound and Walker 1986).

Flower thrips have often been associated with pollination (Ananthakrishnan *et al.* 1981), especially where other pollinating insect species are absent (Hagerup 1950) or where the morphology of the flower makes pollination by large insects difficult (Hagerup and Hagerup 1953).

THE NEW ZEALAND FLOWER THRIPS

Norton (1984) stated that *T. obscuratus* was probably involoved in pollination of some self-compatible hermaphroditic endemic plants. Some pollination of kiwifruit flowers is probably facilitated by *T. obscuratus* (Palmer-Jones and Clinch 1974).

4.2 THRIPS AS PESTS OF CULTIVATED PLANTS

THYSANOPTERA

Thrips are well-known as pests of cultivated plants. Both Lewis (1973) and Bournier (1983) describe plant injury and crop losses associated with thrips. Smith (1967) has distinguished five different kinds of insect damage to plants, of which thrips can cause at least four. Types I and II may be considered as indirect damage in that the insect does not attack the part directly used by humans. Types III, IV and V are kinds of direct damage.

Type I - Loss of Productive Capacity. The insects feed on plant parts (e.g., leaves, roots, stems) and damage the plant but do not kill it. The vigour, longevity or 'productive capacity' of the plant is reduced. With thrips there is often no loss of total leaf area, but the photosynthetic capacity of the leaves is reduced due to the removal of chlorophyll (e.g., *Thrips tabaci*, Cottier 1956) and distortion of leaves (e.g., *Teucothrips disjunctus*, Somerfield 1984). Water loss through feeding punctures on corms (e.g., *Thrips simplex*, Somerfield 1984) or severely infested leaves (e.g., *Thrips tabaci*, Cottier 1956) may also be important.

Type II - Loss of Stand. The insects destroy the entire plant and the plant stand is reduced. This occurs with thrips most often when seedlings are attacked (e.g., *Heliothrips haemorrhoidalis*, Zondag 1977) or in dry seasons when plants lose water rapidly through the damaged epidermis.

Type III - Direct Damage. The insects directly damage or destroy the part of the plant used by humans (e.g., leaf, fruit, seed, fibre). Symptoms of *Thrips tabaci* attack on vegetable crops include silvered areas of foliage and a blistered appearance in severe infestations (Butcher 1984). Seed production may be reduced in grasses by *Chirothrips manicatus* and in red clover by *Teucothrips disjunctus* (Chapman 1984). Cosmetic damage to citrus fruit is caused by *Heliothrips haemorrhoidalis* and to gladiolus flowers by *Thrips simplex* (Cottier 1956).

Type IV - Product Contamination. The insects contaminate the marketed product. Often hosts of *Heliothrips haemorrhoidalis* and *Thrips simplex* may be contaminated by faeces (Cottier 1956), thereby reducing marketable but not nutritional quality of the product. Presence of thrips (*Heliothrips haemorrhoidalis*) in consignments of export kiwifruit is unacceptable to New Zealand's export markets (Besley 1986).

Type V - Destruction of Stored Products. There is little evidence of thrips damage to stored products, either in New Zealand or overseas.

Vectors. Another important aspect of thrips association with plants is their ability to act as vectors of plant pathogens. There are many reports of viral transmission by thrips but few positive confirmations (Ananthakrishnan 1980). *Thrips tabaci* is a known vector of the Tomato spotted wilt virus in New Zealand

(Cottier 1956). The role of thrips as vectors of bacterial pathogens is probably limited (Ananthakrishnan 1980), but they may be important as vectors of fungi. It is evident that fungal spores can be trapped in the body hairs of many thrips species and transferred to healthy plants (Bournier 1983). However, very few thrips-borne fungal diseases have been experimentally demonstrated (Ananthakrishnan 1980).

THE NEW ZEALAND FLOWER THRIPS

As with many thrips, attention was first drawn to *T. obscuratus* because of its economic importance. Crawford (1941) described and named the thrips when it was reported to be doing considerable damage to flowers of grapes in a small area of Auckland, New Zealand. Earlier, Muggeridge (1933) reported the presence of an *Isoneurothrips* sp. (= *Thrips*) in a survey of the Thysanopteran fauna of orchards. This was probably *T. obscuratus*, as other known *Isoneurothrips* spp. were either clearly identifiable at the time or found in very low numbers with restricted host plants. Doull (1949) referred to *Isoneurothrips obscurus* Crawford, obviously a misprint for *obscuratus*. The author stated that this insect was a serious pest of fruit trees.

Other references mention *T. obscuratus* as a pest of youngberry (*Rubus* sp.) (Helson 1952), report that it may reduce seed production in *Phormium* spp. (Cumber 1954, Mound and Walker 1982) and associate it with distortion of young growth on the passion vine (*Passiflora edulis* Sims) (May 1963).

Apart from Harris (1980), who reported potential podset reduction in *Lupinus angustifolius* L., recent literature on the pest status of *T. obscuratus* has concerned damage on nectarine fruit (Anon 1979, 1980) and contamination of export produce, especially cut flowers (Chapman *et al.* 1985, Carpenter 1987) and stonefruit (Mound and Walker 1982). Full records of export produce contaminated by *T. obscuratus* are listed in Appendix 2.

4.3 THRIPS AS PESTS OF STONEFRUIT

FLOWERS

Overseas. Several species of thrips have been associated with damage to stonefruit at flowering (see Table 2.1). The presence of large numbers of thrips in stonefruit flowers may result in fruit drop due to thrips feeding on the stamen filaments and the style (Zeck and Noble 1932, LaRue *et al.* 1972, Bournier 1983). More commonly, feeding damage on the ovaries and small fruit results in irregularly-shaped blocks of russet, sometimes associated with scarring. When feeding occurs at an early stage of ovary development the fruit is also deformed (Bournier 1983). Gummy deposits may also be associated with the damaged fruit (Kourmadas *et al.* 1982, Bournier 1983).

There have been few quantitative studies to determine the level of thrips infestation at different stages of flower development and to relate this to damage. Cravedi *et al.* (1983) sampled adult thrips throughout flower development but not larvae. Nevertheless, other reports of thrips on stonefruit flowers reveal a consistent pattern of infestation. As soon as the stonefruit flowers appear at 'pink', adult thrips migrate from other flowering plants nearby (Bailey 1938, Black *et al.* 1963, LaRue *et al.* 1972, Kourmadas *et al.* 1982). Adults feed in the flowers (Bailey 1938) and lay eggs in the tender flower tissues such as

peduncles, sepals, stamen filaments, stigmas and ovary styles (La Rue *et al.* 1972, Bournier 1983, Cravedi *et al.* 1983, Cravedi and Molinari 1984). Larvae hatch and remain feeding inside the flower (LaRue *et al.* 1972, Bournier, 1983). Adult thrips appear to be most numerous around 'full bloom' (Cravedi *et al.* 1983) and larvae are thought to be most common after full bloom (Bailey 1938). Thrips are protected on young fruit by floral tissues until these fall to the ground (Allman 1948b). The critical period for damage occurs when larval feeding concentrates on the ovary between 'petal fall' and 'shuck fall' when other floral tissues become desiccated (Bailey 1938, LaRue *et al.* 1972, Bournier 1983, Cravedi and Molinari 1984).

Although russet is sometimes found on peaches (Bournier and Blache 1956) and apricots (Bailey 1938), nectarines are thought to be particularly susceptible to feeding injury because they have smooth skin and the floral tissues stick tightly to the developing fruit, providing protection for the thrips larvae (Bailey 1938).

New Zealand. Kemp (1959) reported some nectarine fruit to be malformed, spotty and cracked, often with gum exudation. McLaren described nectarine fruit damage consisting of irregularly-shaped blocks of russet on otherwise clean fruit, together with distortion where russetting was severe. Fine scar lines were also apparent (Anon. 1979).

Kemp (1959) considered that fruit injury might be caused by peach silver mite (*Aculus cornutus* (Banks)) or capsid bug feeding, but did not rule out the possibility of other insects being involved. Surveys of nectarine flowers over several seasons in Central Otago by McLaren (1980-1982) failed to find peach silver mite or capsid bugs, but thrips were present. Bagging experiments on flowers, enclosing and excluding *T. obscuratus* and *Thrips tabaci* adults, verified that thrips were the causative agent of nectarine fruit damage (McLaren 1981-87). *T. obscuratus* was the most common species present during the nectarine flowering period over several seasons (McLaren 1984-86).

T. obscuratus adults have been found inside enclosed nectarine flower buds at pink (McLaren 1986), and thrips were present in the flowers and on the small fruit as long as some dead flower parts remained (McLaren 1980). Eggs of *T. obscuratus* have been observed in the nectary of the nectarine flower (McLaren 1983) and under the epidermis on the outside calyx of apricot flowers (McLaren 1986). Larvae have been observed in very protected positions inside the nectarine flower (McLaren 1983), on young fruit (McLaren 1981) and inside apricot flowers (McLaren 1986). On nectarine, larvae were found on fruitlets throughout October and November (McLaren 1981).

McLaren (1986) found that the most severe damage by thrips occurred between full bloom and petal fall with bagging experiments of adult thrips. These results conflict with overseas work which suggested that the most important time for fruit damage was slightly later, between petal fall and shuck fall and as a result of larval feeding. Although McLaren has observed larvae within stonefruit flowers and on small fruit, it appears that she never identified their presence at petal fall as a major cause of damage.

The extent of nectarine fruit damage varied with ground cover, insecticide regime and season (Kemp 1959, McLaren 1982). Wind has been associated with russet on nectarines, but was not considered as important as thrips feeding (McLaren 1981, 1986). Nectarine trees not treated with insecticides were severely affected, some to such an extent that no saleable fruit was produced (Kemp 1959). McLaren (1982) estimated that 30% of export fruit was rejected due to russet damage by thrips in sprayed blocks.

TABLE 2.1: RECORDS OF THRIPS AS PESTS OF STONEFRUIT AT FLOWERING.

Species	Fruit*	Location	Reference
Frankliniella intonsa	N	Greece	Kourmadas *et al.* 1982
	N	France	Bournier 1983
Frankliniella minuta	ANP	California	Bailey 1938
Frankliniella moultoni	ANP	California	Bailey 1938
Frankliniella occidentalis	ANP	California	Bailey 1938
			Black *et al.* 1963,
			LaRue *et al.* 1972
Taeniothrips inconsequens	NP	California	Bailey 1938
	NP	France	Bournier 1983
Taeniothrips meridionalis	N	Italy	Cravedi *et al.* 1983
	N	Greece	Kourmadas *et al.* 1982
	NP	France	Bournier 1983
Thrips flavus	NP	France	Bournier 1983
Thrips imaginis		New Sth. Wales	Zeck & Noble 1932
	N	New Sth. Wales	Allman 1948b
Thrips major	N	Italy	Cravedi *et al.* 1983
Thrips meridionalis	NP	France	Bournier 1983
Thrips minutissimus	NP	France	Bournier 1983
Thrips obscuratus	N	New Zealand	McLaren 1981-87

* N=Nectarine, P=Peach, A=Apricot

Russet was the most important defect of export nectarines in Central Otago (McLaren 1982) and Canterbury (Brooks 1985).

Damage to peach fruit is not common in New Zealand (Kemp 1959), and even though thrips eggs and larvae have been found in apricot flowers the fruit were not damaged (McLaren 1986).

FRUIT

Overseas. Records of thrips infesting stonefruit at harvest time are scarce. In California LaRue *et al.* (1972) reported that as well as causing feeding damage at flowering, *Frankliniella occidentalis* may cause additional cosmetic injury to highly-coloured early maturing nectarines. Two to three weeks before picking adult thrips migrated from tree terminals, other crops and weeds and laid eggs on the surface of the rapidly growing and maturing fruit. Hatching larvae were found sheltering beneath leaves that were in contact with the fruit. According to Pollini and Giunchi (1979) females of *Thrips major* laid numerous eggs in the flesh of 'Fantasia' nectarines in Italy. The eggs were completely buried in the flesh of the fruit in the peduncle zone. Hatched larvae gathered at points where the fruit contacted branches or leaves. The feeding of both thrips species led to typical thrips damage in the form of discolouring, russetting and speckling of the fruit, thus spoiling fruit appearance.

LaRue *et al.* (1972) speculated that thrips were attracted by either colour changes (green to red) or the characteristic nectarine aromas which become apparent shortly before picking.

New Zealand. Thrips adults, especially *T. obscuratus*, are known to infest ripe stonefruit including peaches, nectarines and apricots, and have become important contaminants of fresh export fruit (Spiller 1951, McLaren 1980, 1982, Penman *et al.* 1982). There has been very little published on the extent of thrips infestation or any description of damage. Larvae of *T. obscuratus* have been found on the skin of ripe peaches (McLaren 1986) that have hatched from eggs laid within the peach skin (McLaren pers. comm.).

Thrips infestation of ripe stonefruit is particularly important, as produce for export markets must be almost entirely free of insect contamination. Currently there is a 1% tolerance for Australia and 2% tolerance for the rest of the world for live thrips on stonefruit (Anon 1988a). It has been claimed that up to 90% of New Zealand stonefruit imported into Australia by air was fumigated for thrips, mites and leafrollers (Johnston 1985). *T. obscuratus* is a problematic contaminant because it is small and endemic to New Zealand. Bollard (1981) listed thrips control on export fruit as a 'top priority', having a large actual or potential effect on production or marketing.

TERMINAL SHOOTS

Thrips have been reported in large numbers on the terminal shoots of peaches and nectarines (La Rue *et al.* 1972, Pollini and Giunchi 1979). In California, *Frankliniella occidentalis* damages the terminals so that new and undesirable growth occurs in the buds below the terminal. The result is extreme branching which necessitates further pruning. This problem has not been reported in New Zealand.

5 CONTROL STRATEGIES

Summaries of methods for controlling thrips in general are found in Lewis (1973) and Bournier (1983). This review is specifically concerned with thrips control on stonefruit.

5.1 CHEMICAL CONTROLS

Most non-chemical control methods have proved ineffective at controlling thrips, so chemical control is usually necessary (Bournier 1983). As new products are being constantly developed and others removed from the market, there is little point detailing active ingredients and dosages. In general, contact insecticides with a fumigant action have been most effective against thrips, especially those that hide inside crevices within the plant. Systemic insecticides are seldom used (Bournier 1983).

FLOWERS

Thysanoptera. A number of different chemicals have proven effective at controlling thrips on stonefruit at flowering. These include kerosene emulsions (Zeck and Noble 1932), plant extracts such as rotenone, derris and pyrethrum (Bailey 1938), organochlorines such as DDT (Allman 1948a), many organophosphates (Black *et al.* 1963, LaRue *et al.* 1972) and some carbamates such as formetanate and methomyl (LaRue *et al.* 1972).

Chemical applications at intervals ranging from 3 to 6 days throughout the flowering period have given good control of thrips (Zeck and Noble 1932, Black *et al.* 1963). Alternatively, chemicals have been directed at the invading adults at pink and sometimes full bloom, or the larvae at petal fall. It is generally considered that larval damage is more critical, so the petal fall application is important (Bailey 1938, Allman 1948b, Bournier and Blache 1956, 1970, Kourmadas *et al.* 1982, Cravedi *et al.* 1983).

Thrips are well hidden inside the flower and it is not necessarily the most toxic chemical that is most effective. Chemicals with high vapour pressures penetrate the flowers better (Black *et al.* 1963, Bournier 1970) and chemicals with residual activity help reduce reinfestation during flowering (Zeck and Noble 1932).

Bee poisoning during flowering is another important consideration. Chemical applications have been limited, sometimes by legislation, to times when bees are not active on flowers during bloom (Bournier 1983) or to chemicals with low hazard to bees (Black *et al.* 1963, Bournier 1970). Stonefruit flowers are self-fertile so that the presence of pollinators is not necessary for pollination, but bees are often present in the orchards during flowering (LaRue *et al.* 1972). Some chemicals or formulations may cause burning and defoliation of the fragile flowers (Zeck and Noble 1932, Bournier 1970) and others may be unsafe for humans reentering orchards (LaRue *et al.* 1972). Therefore a particular chemical may be suitable at different times over the flowering period (LaRue *et al.* 1972).

The effect of chemicals on beneficial invertebrates such as mite predators may also be important (LaRue *et al.* 1972). Chemical applications for thrips control have coincided with control of aphids (Bournier and Blache 1956, Cravedi and Molinari 1984) and other pests (Kourmadas *et al.* 1982).

Threshold levels for control are low. Serious losses of nectarines have been sustained from initial thrips populations of less than one adult thrips per blossom (Allman 1948b). Bournier (1970) considered that the presence of one female per flower at full flowering justified intervention, but Cravedi *et al.* (1983) considered that even the sporadic presence of adults at pink required treatment. Treatment may be unnecessary or of little economic value when there is less than one thrips larvae per blossom late in the bloom period (Black *et al.* 1963).

The New Zealand Flower Thrips. Although he was unsure of the damaging pest, Kemp (1959) found that the fruit of nectarine trees treated with either methyldemeton or endrin at pink and petal fall were almost completely free from damage.

McLaren (1980-1987) carried out intensive trials to determine the best chemicals for thrips control at flowering, and also the most appropriate timing of applications in accordance with the registration or likely registration of chemicals over this time. The recommended spray programme for 1986-87, based largely on these trials, included insecticide applications at bud movement (oil and lindane) and petal fall (chlorpyrifos or demeton-s-methyl) followed by two further sprays at 10 day intervals (azinphosmethyl or chlorpyrifos). A treatment at full bloom was recommended (McLaren 1984), but as a precaution against bee poisoning no chemicals have been registered for use at this time. A chemical application at pink was not generally worthwhile so it was deleted from the programme (McLaren 1983). During warm springs the azinphosmethyl sprays were found to be unnecessary (McLaren 1987).

FRUIT

Thysanoptera. There is little published information on chemical control of thrips on the fruit of stonefruit. LaRue *et al.* (1972) conducted trials with several chemicals not registered for the control of thrips. These were applied 3 weeks before picking and were ranked according to effectiveness.

The New Zealand Flower Thrips. Research on the control of thrips on ripe stonefruit was initiated in 1980-81 (McLaren 1982). Research on preharvest controls has attempted to find the most suitable chemicals (McLaren 1982, 1983), rates (McLaren 1983, 1984) and timing of insecticide spray applications. Carbaryl and maldison have proved the most effective insecticides for thrips control (McLaren 1985). Both chemicals have short persistence (O'Conner 1987), and export withholding periods are one day for carbaryl and seven days (28 for Europe) for maldison (K Yates pers. comm.). Both chemicals are known to have a continuing effect on thrips after picking when fruit is in the coolstore (McLaren 1985). This is an important attribute when thrips continue to invade the crop after treatment. Carbaryl is the insecticide currently recommended for use at preharvest, as it has a shorter withholding period than malathion.

The stonefruit spray programmes recommended by the Ministry of Agriculture and Fisheries did not include control for thrips (either at flowering or harvest) until the 1985-86 season when the programme stated: 'For thrip(s) control during harvest use carbaryl'. Only the 1987-88 MAF Export Stonefruit spray programme gave specific recommendations for control on ripe fruit. Applications of carbaryl were recommended at 14 days before harvest, at preharvest and at 7-day intervals during harvest. Where

stonefruit blocks are composed of several different varieties, as many as seven carbaryl applications may be needed throughout the harvest period.

Field treatments do not give complete control of adult and larval thrips on peaches and nectarines (McLaren 1986). Therefore various methods of postharvest treatment have been attempted. These include placement of dichlorvos strips in the packing case (McLaren 1982), physical removal of thrips by blasting with air (McLaren 1983b), dipping into insecticide and fungicide solutions (McLaren 1982, 1983b, 1984, 1985, 1986, 1987) and the use of controlled temperatures and fumigation (McLaren 1988). Dips of maldison and triforine show potential for control of adults and larvae (McLaren and Dale 1987). Fumigation effectively kills adults and larvae of *T. obscuratus* on fruit (McLaren 1988), although several specimens of *Haplothrips* sp. have survived.

5.2 BIOLOGICAL CONTROL

Numerous parasites and predators contribute to a significant reduction in pest thrips populations (see Section 3.9) but so far biological control has not proven to be an efficient control method (Bournier 1983). There have been few deliberate attempts to introduce natural enemies to discourage pest species (Lewis 1973). There are no reports of thrips populations being reduced on stonefruit by biological control in New Zealand or anywhere else.

5.3 CULTURAL CONTROL

In spring thrips migrate onto nectarine trees from the flowers of cover crops and weeds in or near the orchard. Removal of these sources of infestation before bloom, forces adult thrips to find hosts elsewhere, kills the larvae and causes migration of pupae that reach eclosion (Bailey 1938). Host removal is especially successful with large areas of stonefruit trees. Weed control or cultivation during bloom results in a thrips population disturbance and rapid migration to nectarine flowers (La Rue *et al.* 1972).

Similarly, in Central Otago nectarine blocks which showed the cleanest fruit were cultivated in the spring, and where cultivated blocks produced scarred fruit it was found that cultivation had taken place during flowering (Anon. 1979).

Zeck and Noble (1932) noted a considerable varietal difference in fruit set of thrips-infested flowers. This was considered to be partly due to the variation in structure of the flowers, a variety with more robust stamens and pistils tending to withstand the attack of thrips and so to set more fruit.

Kemp (1959) indicated that there may be some varietal differences in nectarine fruit damage in New Zealand. 'Cardinal' and 'John Rivers' were two varieties which sometimes showed severe symptoms.

5.4 NATURAL CONTROL

In the field the interdependent effects of temperature and rainfall are the two most important factors affecting the number of thrips (Lewis 1973). Temperature influences the rate of development and

oviposition (see above). Heavy rainfall causes high mortality to a number of thrips species, as they may be washed from the host plants or drowned in the soil. Alternatively some species survive better in damp rather than dry conditions (Lewis 1973). Very low or high levels of soil moisture are lethal to thrips that pupate in the soil (Andrewartha 1934, Bailey 1938).

6 PEACH AND NECTARINE CULTIVATION

This section is a brief introduction to the stonefruit industry. It also summarises aspects of stonefruit production such as management practices, pests and diseases and fruit and flower development. These are important considerations in the development of control stategies for thrips.

6.1 PRODUCTION

Peaches and nectarines (*Prunus persica* (L.) Batsch.) belong to the family Rosaceae along with plum, prune, cherry, apricot, almond and many species used only as rootstocks or ornamentals. The nectarine (var. *nectarina*) is merely a peach with recessive genes that result in fuzzless fruit (Westwood 1978).

Peaches and nectarines are grown for both the fresh fruit and processing markets. World production was over 7 million tonnes in 1981, with 40% from Italy and the United States (Jackson 1986c).

New Zealand is fortunate in having a climate suitable for the production of a number of types of stonefruit (Wilton 1984). Their total area in 1985 and export earnings in 1987 were: nectarine (1042 ha, $5.8 m), peach (753 ha, $1.2 m), apricots (546 ha, $1.0 m), cherries (236 ha, $1.2 m) and plums (141 ha, $0.06 m) (Anon 1986, 1988b). Traditionally nectarine and peach production was aimed at the local market, with some processing (mostly canned peaches) and export (Wilton 1984). The peach canning industry is now declining and its future is not promising (Jackson 1986c). According to Jackson (1986c), about 10% of nectarines and a small percentage of peaches are exported. However, there has been a marked increase in plantings of export stonefruit varieties since 1980 (Shepherd 1984), with a forecasted nectarine export production increase of 100% between 1984 and 1988 (Anon 1985a). Export earnings of fresh nectarines and peaches have increased 56% from 1984 to 1987 (Anon 1986, Anon 1988b).

Peaches are grown throughout the country, but nectarine production has been centred in Hawkes Bay and Central Otago (Wilton 1984). Large areas of nectarines have been newly planted in Hawkes Bay/Poverty Bay, Waikato/Bay of Plenty and Otago, and peaches throughout the main growing areas (Shepherd 1984). There have also been significant new plantings of stonefruit in Canterbury aimed at the late-season Australian market (Hughes 1985). In New Zealand fresh stonefruit is harvested from November to April. Harvest dates for a particular location can be staggered with a selection of different varieties of nectarines and peaches. Ripening dates in Auckland and Hawkes Bay are usually 1-2 weeks earlier than Marlborough and Nelson, and 3 weeks earlier than Central Otago (Wilton 1984). Staggered harvesting dates throughout the country allow for a continuity of supply to both export and local markets.

. Varieties of peach and nectarine are selected for a number of criteria. The crop must be suitable for the locality, crop regularly, have adequate handling and storage ability, show a reasonable tolerance to pests and diseases and be competitive with fruit from other areas. Ideally dessert peaches are large, uniformly round, firm and yellow fleshed, with free stones and an attractive bright reddish-crimson blush. The yellow-fleshed canning clingstone peaches typically have a firm rubbery texture and little or no skin blush (Glucina 1979). Good dessert nectarines have similar characteristics to dessert peaches.

6.2 MANAGEMENT

Stonefruit trees are not-long lived in New Zealand because of silverleaf (*Chondrostereum purpareum* (Pers. ex Fr.) Pouz.). Orchards may have an economic life of only 10 years in the humid north, but up to 20 years in the south (Jackson 1986c). A recent trend to closer planting of trees reduces the time to first harvest and full production. The reduced period of juvenility allows short-term crop rotation, which overcomes silverleaf problems and allows growers to respond quickly to market demands for particular varieties (Jackson 1986c).

Under good conditions trees normally set too much fruit (Westwood 1978), so hand thinning is necessary. There is a tendency for trees to bloom more lightly following a heavy crop year (Westwood 1978).

Grass is often grown in a strip between the trees, and herbicides are sprayed directly beneath the trees to reduce vegetation (Jackson 1986c). Fruit is hand-picked at a stage of maturity consistent with the eventual market: riper fruit for closer local markets and an earlier stage of maturity for more distant markets (Jackson 1986c). Cool storage of nectarines and peaches is restricted to about 3 weeks (Lill and Wood 1983), and immediate reduction of fruit temperature after picking assists transport and marketing (Jackson 1986c).

6.3 PESTS AND DISEASES

To compete on export markets, New Zealand stonefruit must be of premium quality. The local market can absorb a certain amount of down-graded fruit, but with increased stonefruit production local demand may be unable to cope. For these reasons increased production must consider quality as well as quantity (Brooks 1975). Export fruit must be free from pest damage and contamination (Tomkins 1985).

Insect pests reported for peaches and nectarines in New Zealand since 1952 are listed by Helson (1952), Kemp (1971), Penman (1976, 1984), Tomkins (1985), Anon. (1985b) and Cruiskshank (1987). Table 2.2 lists the main insect pests of stonefruit according to plant parts they attack, their pest status and damage. 'Key' pests are those requiring continuous control in order to grow a crop which gives maximum returns. The tolerance of damage from these pests is very low, effectively zero for export-quality fruit. 'Occasional' pests are those requiring only periodic control. Some pests are 'secondary induced' because in the absence of the controls for key pests they may be controlled by natural enemies.

TABLE 2.2: CLASSIFICATION OF NEW ZEALAND STONEFRUIT INSECT PESTS.

Plant Parts Attacked	Pest Status	Damage Type
Fruit (direct damage)	**Key Pests**	**Chewing**
Lightbrown apple moth	Leafrollers	Leafrollers
Brownheaded leafroller	Oriental fruit moth	Oriental fruit moth
Greenheaded leafroller	N.Z. flower thrips	Grass grub
N.Z. flower thrips		Cherryslug
Oriental fruit moth		
Earwigs		
Green peach aphid		
Foliage (indirect damage)	**Occasional Pests**	**Sucking**
Leafrollers	Earwigs	N.Z. flower thrips
European red mite	Mealybugs	Mites
Two spotted spider mite	Grass grub	Scales
Mealybugs	Cherryslug	Mealybugs
Green peach aphid		Green peach aphid
Cherryslug		
Grass grub		
Branch/Shoot/Root	**Secondary Induced Pests**	**Cosmetic**
San José scale	Mites	N.Z. flower thrips
Oystershell scale	Scales	Mealybugs
		Scales

Common names according to Ferro *et al.* (1977).

Economically important diseases of stonefruit are: silverleaf (*Chondrostereum purpureum*), blast (*Pseudomonas syringae* van Hall), brown rot (*Monilinia fructicola* (Wint.) Honey), leaf-curl (*Taphrina deformans* (Berk.) Tul.) and bacterial spot (*Xanthomonas pruni* (Erw. Smith) Dow.) (P Elmer pers. comm.).

Orchard pest control relies heavily on the use of chemical sprays (Penman 1984) which are considered necessary for successful stonefruit production (Jackson 1986c). Recommended spray schedules for peaches and nectarines are published yearly by the Ministry of Agriculture and Fisheries.

'Acceptable quality levels' for New Zealand produce are established by export markets indicating the amount of damage and pest infestation acceptable. The New Zealand Summerfruit Industry has established export 'Grade Standards' designed to cover all summerfruit exports from New Zealand. These are based on 'gazetted' standards in accordance with the Fruit and Vegetable Regulations 1975 of the Plant Act 1970 (see Appendix 17). Standards are now being developed for the local market (Quirke 1988). Copies of the gazetted Grade Standards and Acceptable Quality Levels are available from regional Ministry of Agriculture and Fisheries offices.

6.4 FLOWER AND FRUIT DEVELOPMENT

FLOWER

Flower buds are produced laterally on one-year-old shoots. Normally two flower buds surround a leaf bud. Flowers are hermaphrodite and perigynous. The flower has 5 sepals, 5 petals, a single carpel and numerous stamens, and is sessile (see Figure 2.1) (Jackson 1986c). Almost all varieties are self-fertile. Before entering the dormant period for winter, the floral primordia develop to the stage where the petals, sepals, anthers and pistils are clearly evident (Tuffs and Morrow 1925). In spring the flower bud starts to swell. When the bud scale starts to separate the green flower sepals can be seen underneath. This stage has been labelled bud movement (see Plate 4). As the flower buds continue to expand the pink/red petals appear between the sepals, still tightly enclosing the rest of the flower parts. This is known as pink (see Plate 4). The petals gradually open and at full bloom the stamens and pistil are exposed. The cup-shaped hypanthium, consisting of undifferentiated tissue of sepals, petals and filaments, surrounds but is not attached to the ovary (Jackson 1986a). During full bloom the anthers open and allow the pollen grains to escape (see Plate 1). Pollen release in peaches lasts from one to five days (Jackson 1986b). After fertilization of the ovary, hormonal stimulus from the young developing embryo prevents the fruit from abscissing and causes the ovary to enlarge. Petals begin to wilt (Westwood 1978) and the hypanthium ceases to develop (Jackson 1986b). Petal fall is accomplished with the abscission of the petals from the flower (see Plate 1). From petal fall onward the hypanthium begins to dry out (Bournier 1983) and ultimately breaks away from the receptacle. It may remain tightly adhering to the tip of the fruit (Bailey 1938) or be split in half by the developing fruit. It finally drops from the fruit at shuck fall.

In New Zealand flower buds open about mid-September followed by leaf buds several days later (Jackson 1986c). The flowering period lasts at least seven weeks in Central Otago (McLaren 1980).

FIGURE 2.1: STRUCTURE OF STONEFRUIT FLOWER (after Jackson 1986a).

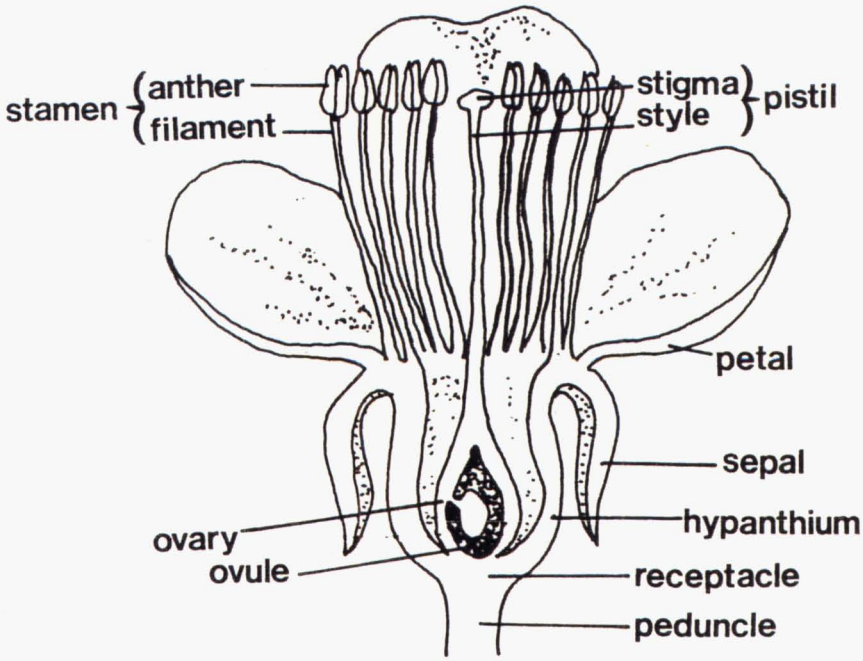
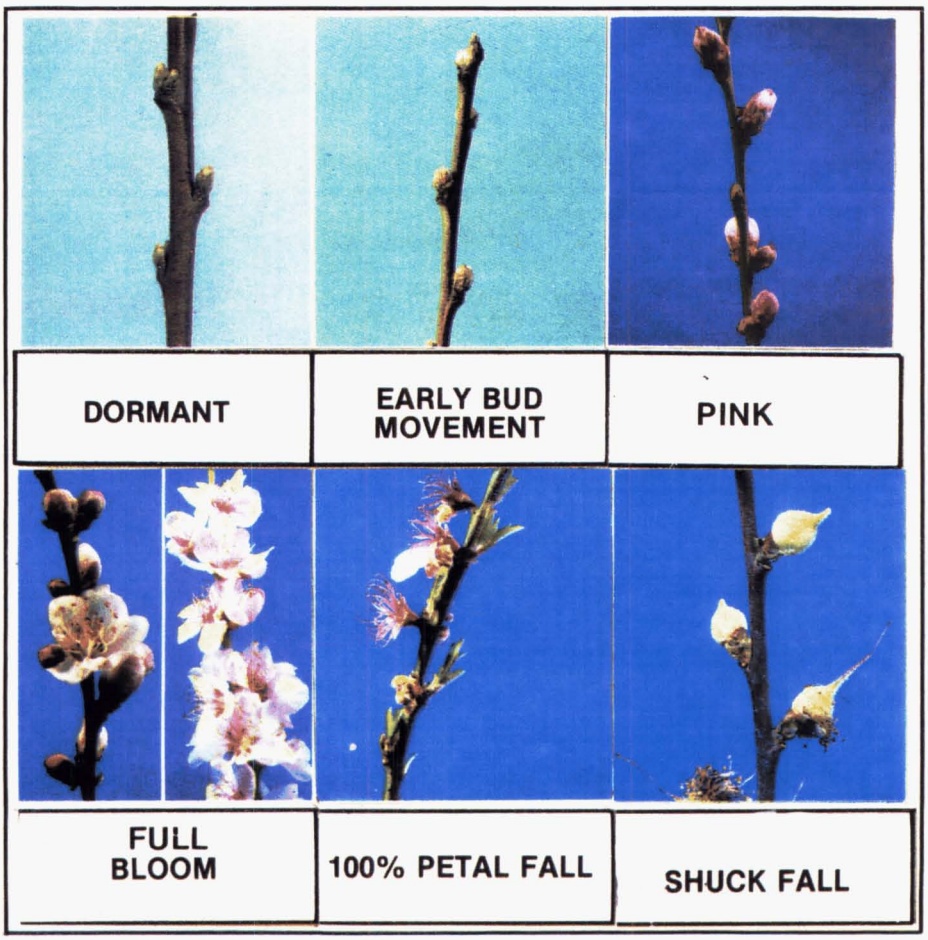


PLATE 4. STAGES OF STONEFRUIT FLOWER DEVELOPMENT.



FRUIT

The fruit is a drupe derived from a single carpel with three layers and single seeds. The exocarp is thin, the mesocarp fleshy and the endocarp stony (Jackson 1986a). After successful fertilization the peach ovary develops into a small fruit. The cumulative increase in volume after anthesis in peaches is represented by a double-sigmoidal curve with three distinct growth phases (Jackson 1986b). The first slow growth period coincides with the period of pit hardening, when mesocarp and seed growth are suppressed. Near the end of pit hardening, flesh cells enlarge rapidly until the fruit is ripe, after which growth slows down and finally ceases (Westwood 1978). The later phases of fruit development have been studied extensively and summarised by Romani and Jennings (1984) and Zucconi (1986). At this time fruit undergo changes in texture, colour and flavour.

CHAPTER III

LABORATORY REARING OF THE NEW ZEALAND FLOWER THRIPS

1 INTRODUCTION

It is often necessary to rear thrips in controlled environments in the laboratory to study life histories, confirm observations made on their behaviour in the field, and for virus-transmission experiments (Lewis 1973). There have been no life history studies of the New Zealand flower thrips, or indeed of any other thrips native to New Zealand (Mound and Walker 1982). Therefore laboratory rearing techniques had to be reviewed and a method developed for *T. obscuratus*.

Thrips are difficult to rear. They have a remarkable propensity to escape, and the use of small confined cages leads to restricted air movement and condensation to which thrips may stick and die. Decomposing plant material is also a problem. Several approaches to thrips rearing have been attempted, but most of these methods are time-consuming and tedious.

Whole plants have been used by Linford (1932), Laughlin (1971) and Tanigoshi and Nishio-Wong (1981) to produce large numbers of thrips for experimental work. Although these methods most accurately reproduce field conditions and survival is high, it is difficult to keep the conditions constant and to enclose the plants so that thrips cannot escape and yet are easy to observe and count.

Small cages have been used to confine thrips on plant material, usually leaves (Davidson and Bald 1930, Sakimura 1961), but thrips may escape unless the cage is positioned precisely. Another problem is that the interface between cage and leaf is a favoured spot for pupation, where thrips are hard to observe. Small portions of plant material (e.g., leaves or flowers) have been completely enclosed by cages to rear thrips (Bailey 1932, Andrewartha 1936, Ward 1968, Beavers and Ewart 1971, Wang and Chu 1986), but this usually necessitates the periodic renewal of plant material and extra handling of the thrips. Humidity may still be a problem (Evans 1932). Munger (1942) and Tashiro (1967) developed techniques to keep the leaf moist so it would last longer, but the plant material still had to be changed and the cage construction was not simple (Beavers and Oldfield 1970).

Callan (1947) developed a technique of floating leaf discs in water, which has been modified by Sengonca and Gerlach (1983). For rearing inactive thrips this method has advantages, since escape and hiding are minimised. Individual thrips can also be observed easily and leaf discs remain fresh for the duration of the life cycle. However, active larvae appear to walk off the discs and drown (Laughlin 1971), and adults may fly away.

'Fish skin' membranes were used to investigate thrips feeding by Sakimura and Carter (1934). Laughlin (1971) developed a culture method for *Hercinothrips femoralis* using 'Parafilm M' stretched over perspex tubing as an artificial membrane for oviposition. For larval development, leaf discs were supplied which needed to be changed regularly. At no time was there any handling of the thrips larvae with Laughlin's method. All stages were visible at all times and escape was difficult. Murai and Ishii (1982) developed a similar method for several species of flower thrips using 'Sealonfilm' and glass tubes. Honey solution (10%) between Sealonfilm membranes was used for oviposition and feeding, and plant material was supplied as a supplementary food source. Together these sufficed to allow full development of the larvae without replenishment. Although this technique did involve handling newly-emerged larvae, it was much simpler than Laughlin's method and used fewer materials. Pollen was introduced to the diet instead of other plant materials, as it was essential for oviposition and important for larval development.

The method developed by Murai and Ishii (1982) for flower thrips was the most important influence in developing a method for *T. obscuratus*. It fulfilled a number of requirements better than methods: escape was minimised, there was a clear view of all stages, thrips could be reared individually, there was minimal handling of larvae, use of artificial membranes reduced mould problems, the apparatus was simple, cheap and readily available, and the cages could be easily handled. The rearing methods described in this chapter therefore owe much to the work of Murai and Ishii (1982).

In this chapter laboratory experiments are described which established the factors important in oviposition, egg and larval development, reproduction and adult longevity for *T. obscuratus*.

2 MATERIALS AND METHODS

Rearing cages (Figure 3.1) consisted of a perspex cylinder (40 mm x 25 mm dia.), both ends of which were enclosed by parafilm (Parafilm M, American Can Company, Greenwich, CT, U.S.A.). At one end a drop of nutrient medium (about 0.04 ml, see below) was deposited and covered with a further layer of stretched parafilm. The rearing cages were placed on petri dishes in lidded clear plastic boxes (Gallenkamp, London) (229 x 120 x 89 mm) (Figure 3.3). Moistened filter paper placed in the bottom of the box raised the humidity, and grease-proof or filter paper placed on the petri dishes prevented the parafilm sticking to the petri dish. Relative humidity was measured at 100% inside these boxes at several temperatures.

Thrips females placed inside the rearing cage laid eggs in the nutrient solution between the double parafilm membrane. To expose the eggs for hatching, the top layer of the double parafilm membrane was cut around its edge and removed. Hatch rates were highest when the top parafilm layer was removed at the 'red' eye stage of egg development. Excess nutrient medium was absorbed with blotting paper. Rearing containers were then placed on moist filter paper inside a plastic pottle (65 mm high x 70 mm dia.) with a tight-fitting lid (Figure 3.2). Relative humidity was measured at 100% inside these pottles at several temperatures. Eggs were checked daily, and when larvae hatched they were placed in rearing cages

FIGURE 3.1: REARING CAGE FOR THRIPS.

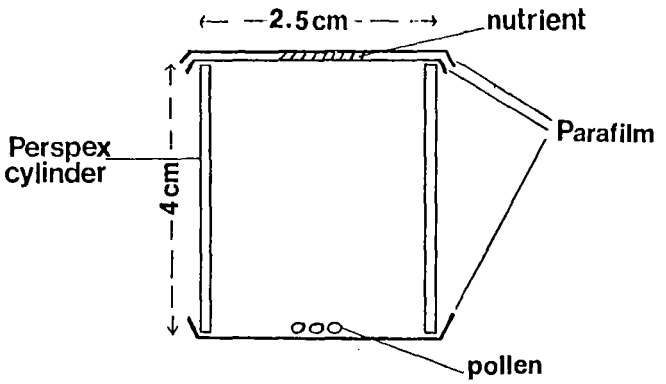


FIGURE 3.2: PLASTIC POTTLE FOR HATCHING THRIPS EGGS.

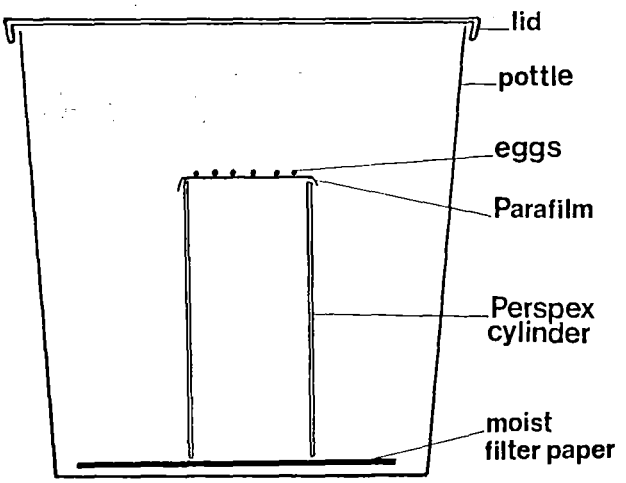
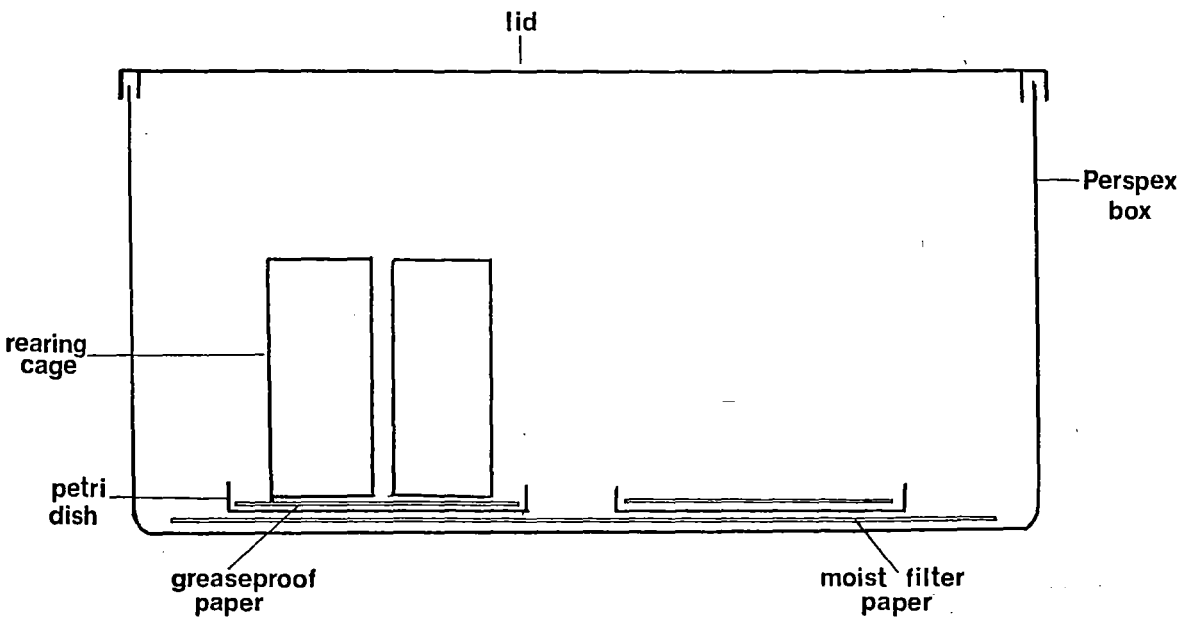


FIGURE 3.3: HUMID PLASTIC BOX FOR THRIPS REARING.



supplied with nutrient medium and pollen with the aid of a fine camelhair brush. These cages were also placed inside humid clear plastic boxes as described previously (Figure 3.3).

The pollen commonly used in these experiments included Iceland poppy (*Papaver nudicaule* L.) collected from the flowers of glasshouse-grown plants, and rose (*Rosa* sp.) and gorse (*Ulex europaeus* L.) from flowers collected in the field. About 0.0006 g of pollen was supplied to each rearing cage. Pollen used was less than a week old, although Iceland poppy pollen kept in laboratory conditions still provided sufficient nutrients for oviposition after six weeks. The nutrient medium was either apple/peach (70/30%) juice ('Fresh-Up' apple/peach juice. The New Zealand Apple and Pear Marketing Board) or 10% sucrose solution. The mould inhibitor used in the nutrient medium in some experiments was a solution of methyl para-hydroxybenzoate (15g), sorbic acid (20g) and 95% alcohol (170ml), at a rate of 1%. Mould often became a problem in nutrient media after about a week if stock solutions were used for too long. Eggs were killed by the presence of mould inhibitor in the nutrient medium.

Adults were transferred between rearing cages with a camelhair brush or by inverting the cage over another and giving both several sharp taps.

2.1 OVIPOSITION

In this section thrips requirements for oviposition in terms of diet and temperature are investigated.

2.2.1 EFFECT OF POLLEN AND NUTRIENT MEDIUM

Female thrips were collected from garden roses and five were placed in each of six rearing cages inside humid plastic boxes in a controlled environment cabinet (20 $\pm$1^{o}C, 16L:8D). From days 1 to 4 thrips were supplied with pollen (Iceland poppy) and nutrient medium (apple/peach juice) daily. Female thrips that died within the first four days were replaced. From days 5 to 12 each cage received one of the following treatments daily:

1. no pollen, nutrient medium (water)
2. no pollen, nutrient medium (10% sucrose)
3. no pollen, nutrient medium (apple/peach juice)
4. pollen, nutrient medium (water)
5. pollen, nutrient medium (10% sucrose)
6. pollen, nutrient medium (apple/peach juice)

From days 13 to 15 each rearing cage received fresh nutrient medium (apple/peach juice) and pollen daily. Iceland poppy pollen was used throughout the experiment.

Eggs laid in the nutrient medium were counted daily. On days 4, 8, 12 and 15, rearing cages from which the females had been removed were replaced in the controlled environment cabinet to establish the percentage hatch rates. The top layer of the double parafilm membrane was removed and the rearing cages

placed in humid plastic pottles to allow the eggs to hatch. Adult females were identified at the end of the experiment.

2.1.2 EFFECT OF POLLEN AND OTHER PLANT TISSUE

Female thrips were collected from garden roses and placed in rearing cages inside humid plastic boxes in a controlled environment cabinet (20 $\pm$1^{o}C, 16L:8D). For four days before the start of the experiment thrips were supplied with pollen (rose) and nutrient medium (10% sucrose) daily. After that on day 1, thrips were placed singly in rearing cages and supplied with nutrient medium (10% sucrose) and pollen (rose). On day 3, each cage was randomly assigned to one of the following treatments, which it continued to receive to day 9. Each treatment was replicated by eight rearing cages containing a solitary female.

1. No pollen
2. Fruit (peach var. 'Redhaven', 5mm dia. X 5mm)
3. Stamen filament (1 rose)
4. Pollen (rose)
5. Fruit (peach var. 'Redhaven', 5mm dia. X 5mm) and pollen (rose).

The fifth treatment was added to test whether eggs were laid preferentially in fruit rather than in the nutrient medium. Thrips were placed in new rearing cages with fresh nutrient medium and either pollen, fruit or stamen every 48 hours, at which time the number of eggs laid was counted. On days 11 and 13 all thrips received the same conditions of nutrient medium (10% sucrose) and pollen (rose). On days 1, 9 and 13, rearing cages from which the females had been removed were replaced in humid plastic boxes in the controlled environment cabinet to determine percentage hatch rates. The top layer of the double parafilm membrane was not removed. All female thrips were identified at the end of the experiment. Thrips that died during the experiment were not replaced.

2.1.3 EFFECT OF TEMPERATURE

Female thrips were collected from garden roses and placed in rearing cages in humid plastic boxes in a controlled environment cabinet (20 $\pm$1^{o}C, 16L:8D) for about one month. Rearing cages were supplied with pollen (Iceland poppy) and nutrient medium (apple/peach juice). Five females were then placed in each of four rearing cages inside humid plastic boxes in controlled environment cabinets (16L:8D) at 10, 15 and 20 $\pm$1^{o}C respectively for eight days and 25 $\pm$1^{o}C for four days. Pollen and nutrient medium were changed daily and eggs laid in the nutrient medium were counted. On days 4, 8 and 12 the eggs in the rearing cages were exposed by removing the top layer of the double parafilm membrane and the rearing cages were placed in humid plastic pottles at 20^{o}C to estimate the percentage egg hatch. Adult females were identified at the end of the experiment. Thrips that died during the experiment were not replaced.

2.2 LARVAL DEVELOPMENT

In this section the requirements for thrips larval development in terms of diet are investigated.

2.2.1 EFFECT OF POLLEN AND NUTRIENT MEDIUM

Sixty newly-hatched laboratory-reared larvae were placed singly in rearing cages with the following treatments (10 larvae per treatment) :

1. no pollen, nutrient medium (water)
2. no pollen, nutrient medium (10% sucrose)
3. no pollen, nutrient medium (apple/peach juice)
4. pollen, nutrient medium (water)
5. pollen, nutrient medium (10% sucrose)
6. pollen, nutrient medium (apple/peach juice)

Rearing cages were placed inside humid plastic boxes in a controlled environment cabinet (20 $\pm 1^{o}$C, 16L:8D). Nutrient media and pollen (Iceland poppy) were not renewed during the experiment. Larvae were observed daily for development and mortality. Mean development time was calculated for larval instars in each treatment for those larvae which developed to the following instar. Sexes were not distinguished. Mortality of prepupae and pupae was also assessed but not development time. Adult females from which the larvae developed were identified.

2.2.2 EFFECT OF POLLEN AND OTHER PLANT TISSUE

Sixty newly-hatched laboratory-reared larvae were placed singly in rearing cages with the following treatments (20 larvae per treatment) :

1. pollen (rose)
2. stamen filaments (2 rose)
3. fruit (peach var. unknown, 5mm dia. X 5mm)

Rearing cages were placed inside humid plastic boxes inside a controlled environment cabinet (20 $\pm 1^{o}$C, 16L:8D). All cages were supplied with nutrient medium (10% sucrose) which was not renewed throughout the experiment. All rearing cages were opened every second day until formation of the prepupae. Fruit and stamens were renewed on these occasions but no new pollen was added to the rearing cages of treatment 1. Larvae and pupae were observed daily for development and mortality. Mean development time (days) was calculated for each instar of both sexes for each treatment for those individuals that developed to adult. Adult females from which the larvae developed were identified.

2.2.3 EFFECT OF POLLEN TYPE

Fifty-seven newly-hatched laboratory-reared larvae were placed singly in rearing cages with one of the following flower pollens:

1. Iceland poppy (*Papaver nudicaule*) (15 larvae)
2. gorse (*Ulex europaeus*) (12 larvae)
3. flax (*Phormium tenax* J.R. et G.Forst.) (15 larvae)
4. *Hebe vernicosa* (Hook. f.) (15 larvae)

The nutrient medium was 10% sucrose with 1% mould inhibitor. All rearing cages were placed inside humid plastic boxes in a controlled environment cabinet (20 $\pm 1^{o}$C, 16L:8D). Larvae and pupae were observed daily for development and mortality. Mean development time (days) was calculated for each instar of both sexes for each treatment for those individuals that developed to prepupa. At this stage the sex of the thrips can be determined. Adults from which the larvae developed were identified.

2.3 DEVELOPMENT AT CONSTANT TEMPERATURES

Between two and ten field-collected female thrips were placed inside rearing cages (nutrient medium: apple/peach juice, pollen: Iceland poppy) inside humid plastic boxes in controlled environment cabinets at either 19 or 20 $\pm 1^{o}$C (16L:8D) to facilitate oviposition. After six hours, females were removed from the rearing cages and replaced in new rearing cages. This process was repeated daily until sufficient eggs for developmental studies had been laid.

The eggs were exposed by removing the top layer of the parafilm double membrane and placed in humid plastic pottles at one of the following temperatures: 10, 15, 19, 20, 23, 25 or 27 $\pm 1^{o}$C in controlled environment cabinets (16L:8D). Eggs were observed daily. Newly-emerged larvae were placed singly in rearing cages (nutrient medium: apple/peach juice, pollen: Iceland poppy) with the aid of a fine camelhair brush. Mould inhibitor was added to the nutrient media at temperatures of 10, 15, 20 and 25^{o}C. The rearing cages were replaced in the same controlled environment cabinet from which they developed as eggs. Larvae were observed daily and development times recorded. Exuviae gave evidence of development to 2nd instar, and prepupae and pupae were clearly distinguished by the descriptions of Mound and Walker (1982). When females matured to adults, rearing cages were resupplied with nutrient medium (no mould inhibitor) and pollen daily until oviposition. At temperatures of 19, 23 and 27^{o}C adult thrips were identified at adult eclosion (males) and after oviposition (females). At 15, 20 and 25^{o}C adult males and females (after oviposition) were supplied with fresh nutrient medium (with mould inhibitor) and pollen, weekly (fortnightly at 10^{o}C) till death when they were identified. Percentage mortality was established at 10, 15, 20 and 25^{o}C for each life stage from egg to pupa. Attempts were made to rear thrips at 30 and 34^{o}C. At both these temperatures eggs failed to hatch, and the few that hatched at 30^{o}C died soon after eclosion.

Lower threshold temperatures for the development stages of egg, combined first and second instar, combined prepupa and pupa, egg to adult and egg to egg (one generation) were established by linear regression on the reciprocal of development time (rate) against temperature. By setting the y value in the straight line equation to zero and solving for x, the theoretical lower threshold temperature of development was calculated (Campbell *et al.* 1974). The thermal constant K was calculated for the above development stages by the reciprocal of the slope of the development rate/temperature equation (y=mx+c where K =1/m).

2.4 REPRODUCTION

Mature second instar larvae were collected from gorse flowers, placed singly in rearing cages (pollen: rose, nutrient medium: 10% sucrose) inside humid plastic boxes in a controlled environment cabinet (20 $\pm 1^{O}$C, 16L:8D) and reared to adult. At eclosion adult females were placed singly in rearing cages freshly supplied with nutrient medium only, until all immature stages reached maturity. With full eclosion, 13 adult females in separate rearing cages were randomly assigned to one of the following two treatments:

1. one male added (6 females)
2. no males added (7 females)

Rearing cages for both treatments were supplied with nutrient medium (10% sucrose) and pollen (rose). Male thrips were collected from garden roses. Before placement in rearing cages in treatment 1, the initial copulation of females and males was observed with the aid of a binocular microscope. Single males were introduced to the solitary virgin females in gelatin capsules (No. 000, Parke, Davis & Company. Sydney), manipulated with the aid of a pin pushed through one end of the capsule. The time to copulate after introduction and time in copula for the initial pairing was established. Females and males were then replaced together in rearing cages in the controlled environment cabinet for one week, as were the solitary virgin females of treatment 2. This time was sufficient for the preoviposition period to be completed (see Table 3.4). Dead males were replaced in the rearing cages of treatment 1 during week 1. All males were removed at the end of the first week. The number of eggs laid over this first week was not established.

Each week females from both treatments were transferred to new rearing cages with fresh nutrient medium and pollen until death. Eggs laid each week were counted and at the conclusion of the experiment the females and males were identified.

On the penultimate day of weeks 1 and 3, females of both treatments were placed in new rearing cages with fresh nutrient medium and pollen for 24 hours. The eggs from these rearing cages were kept until they had reached the 'red eye' stage, when the top layer of the double parafilm membrane was removed. The rearing cages with exposed eggs were then placed in humid plastic pottles. When the eggs hatched, the larvae were placed singly in rearing cages supplied with nutrient medium and pollen and reared to adult. The sex of these adults was then determined.

3 RESULTS

3.1 OVIPOSITION

3.1.1 EFFECT OF POLLEN AND NUTRIENT MEDIUM

The results for the experiment on pollen and nutrient medium requirements for oviposition are shown in Fig. 3.4. For days 1-4, female thrips laid eggs in all rearing cages when supplied with nutrient medium and pollen. When pollen was not replaced in treatments 1, 2 and 3 on the fifth day, oviposition began to decline and on day 10 had ceased in all these treatments. Oviposition continued in treatments where pollen was supplied daily (treatments 4, 5 and 6). When pollen was reintroduced to treatments 2 and 3 on day 13, females soon resumed oviposition at levels comparable with the other treatments. All females died in treatment 1 (water and no pollen) by day 10, though mortality did not exceed 60% in the other treatments. Oviposition rates for sucrose, apple/peach juice and water supplied with pollen were similar. Hatch rates were mostly between 50 and 90% and there was no consistent difference between treatments. Female thrips were identified as *T. obscuratus*.

3.1.2 EFFECT OF POLLEN AND OTHER PLANT TISSUE

The results for the experiment comparing diets of plant tissues on oviposition are shown in Fig. 3.5. Only oviposition values of adults that survived the experiment were used. Mortality of adults was low. Oviposition was similar in all treatments on day 1 when all thrips had been supplied with sucrose and pollen. Those thrips supplied with pollen throughout the experiment (treatments 4 and 5) continued to oviposit at similar rates. In treatments 1, 2 and 3 where there was no pollen, oviposition dropped significantly, and with sucrose only, no eggs were laid on days 5, 7 and 9. When fresh pollen was reintroduced to these treatments on day 11, oviposition soon resumed at levels similar to other treatments. Hatch rates were all above 80% and showed little difference between treatments. There appeared to be no preference for oviposition in fruit, as similar numbers of eggs were found in sucrose and pollen treatments with and without fruit. Female thrips were all identified as *T. obscuratus*.

3.1.3 EFFECT OF TEMPERATURE

Temperature influenced the rate of oviposition. At different temperatures oviposition varied from 2.9 eggs per female per day at 10°C to 8.4 eggs at 25°C (Fig. 3.6). The number of eggs laid per female per 24 hours was plotted against temperature and the results are shown in Fig. 3.6. Linear regression showed a significant relationship between oviposition and temperature. Oviposition decreased with decreasing temperature. Extrapolation of the straight line to the x axis gave a theoretical lower limit of oviposition at 6.9°C. Three thrips died during the experiment, one each at 15, 20 and 25°C. Percentage egg hatch was between 40 and 85%, but showed little consistent difference between treatments. All females were identified as *T. obscuratus* except for one *Thrips australis* female in the 20°C rearing cage.

FIGURE 3.4: MEAN NUMBER OF EGGS LAID PER 24 HOURS BY THE N.Z. FLOWER THRIPS SUPPLIED WITH DIFFERENT DIETS.

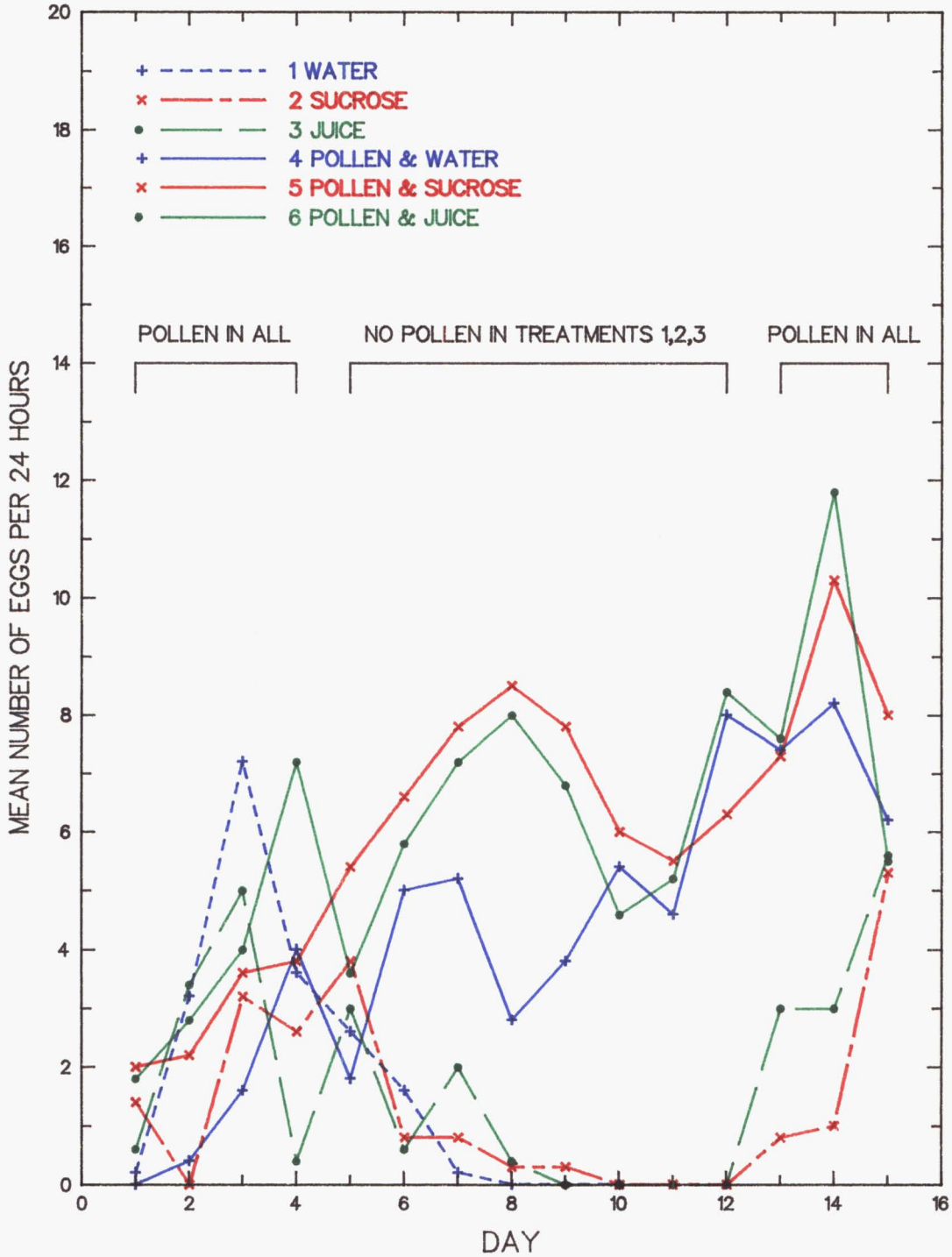


FIGURE 3.5: MEAN NUMBER OF EGGS LAID PER 48 HOURS BY THE N.Z. FLOWER THRIPS SUPPLIED WITH DIETS OF PLANT TISSUES (C.I.=0.05).

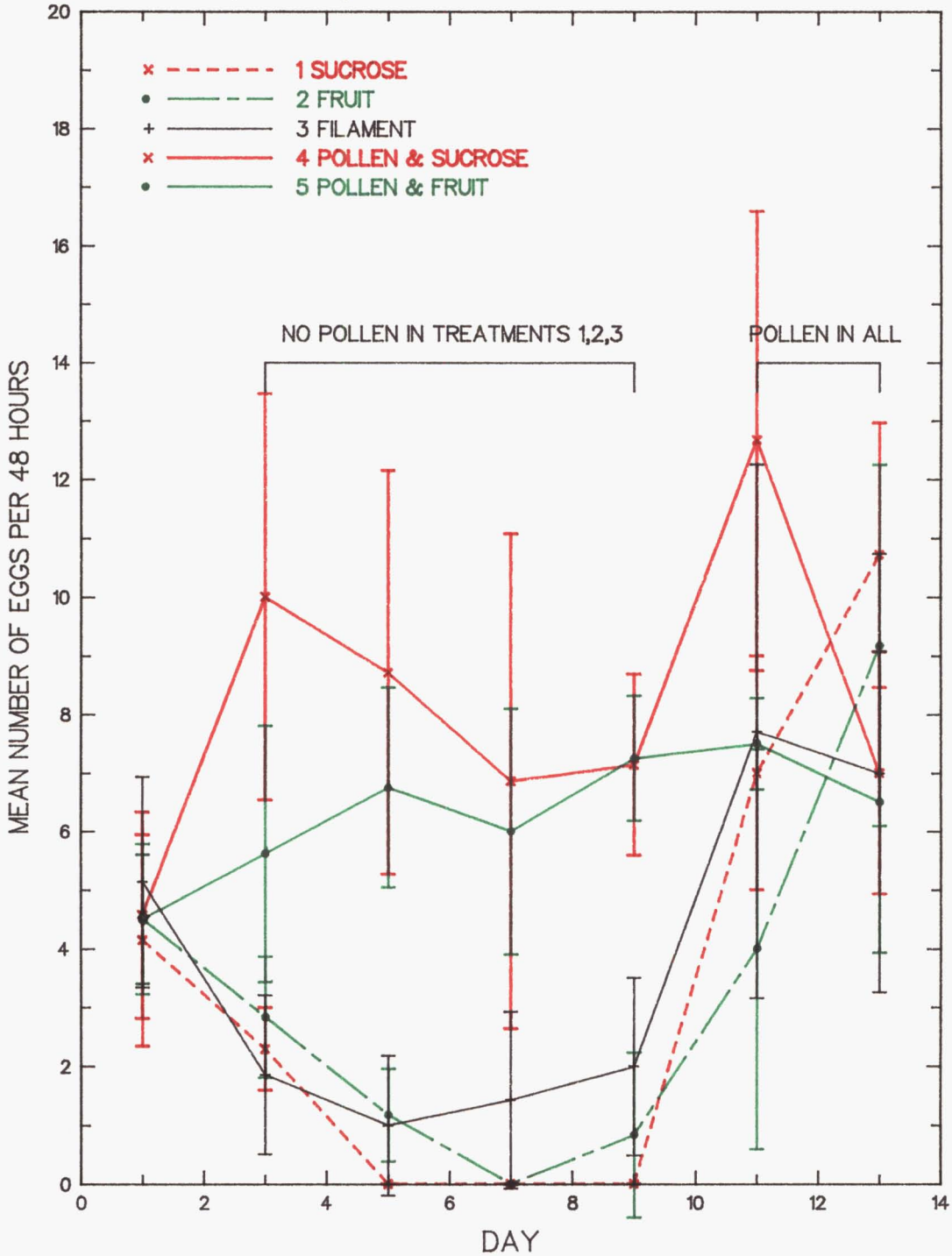
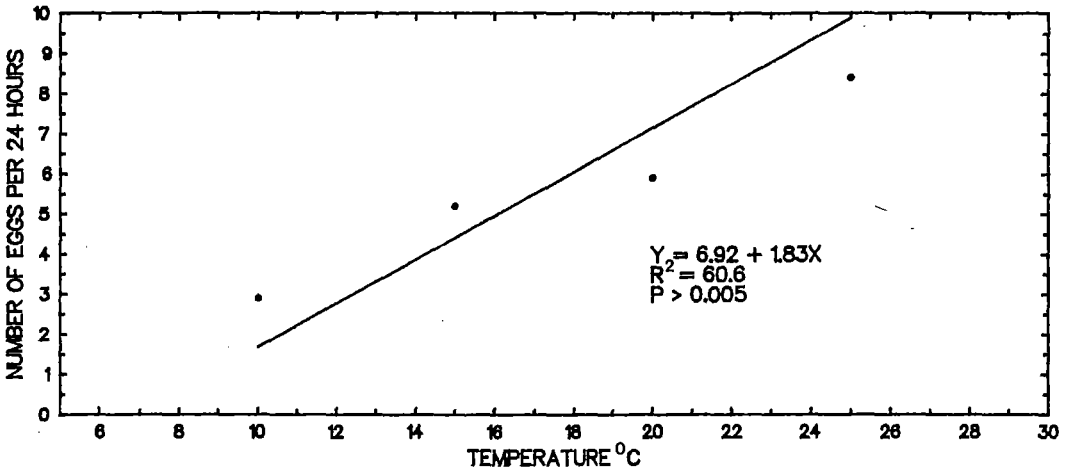


FIGURE 3.6: THE RELATIONSHIP BETWEEN RATE OF EGG PRODUCTION AND TEMPERATURE FOR THE N.Z. FLOWER THRIPS.



3.2 LARVAL DEVELOPMENT

3.2.1 EFFECT OF POLLEN AND NUTRIENT MEDIUM

Comparisons of diets for larval development showed that in all treatments with no pollen, only two 1st instar larvae out of 30 matured to 2nd instar (Table 3.1). None developed to prepupa. In treatment 1 (water) most larvae died within 3 days, but larvae in treatments 2 and 3 (sucrose and apple/peach juice without pollen) commonly survived for up to 10 days. In treatments 5 and 6 (sucrose and apple/peach juice with pollen) most larvae developed to adults. Little difference was observed in development rate between the two nutrient media, allowing for differences in sex. In treatment 4 (water, pollen) mortality was greater than the other pollen treatments, especially during the 2nd instar. Only two developed to adult. All adult females from which the larvae developed were *T. obscuratus*.

3.2.2 EFFECT OF POLLEN AND OTHER PLANT TISSUE

Diets of plant tissues (pollen, stamen filament, fruit) resulted in larval development to adults (Table 3.2). Mortality was low with larvae reared on pollen and stamen filaments (5%), but moderate with fruit (40%). Development rates were slower when pollen was not supplied. For females, development time to adult with larvae feeding on pollen was significantly faster than with larvae feeding on stamen filaments ($t=3.86$, $p<0.0032$, $df=10.3$). Similarly, male larvae feeding on pollen developed to adults significantly faster than male larvae feeding on stamen filaments ($t=4.68$, $p<0.0001$, $df=22.9$) and fruit ($t=4.91$, $p<0.0001$, $df=10.5$). Male larvae feeding on stamen filaments also developed significantly faster than males feeding on fruit ($t=2.77$, $p<0.018$, $df=11.4$). Few females developed on fruit, so that statistical analysis was not attempted. Adults from which the larvae were reared were all identified as <f=2>T. obscuratus<f=1>.

TABLE 3.1: MORTALITY AND MEAN DEVELOPMENT TIME OF THE NEW ZEALAND FLOWER THRIPS REARED WITH AND WITHOUT POLLEN AT 20°C.

	NO POLLEN			POLLEN		
Treatment	1	2	3	4	5	6
	Water	Sucrose	Juice	Water	Sucrose	Juice
1st instar	90* (4.0,-)#	90 (2.0,-)	100	30 (2.3,0.76)	0 (2.2,0.42)	0 (2.2,0.42)
2nd instar	100	100		80 (3.5,0.71)	10 (3.3,0.71)	0 (4.1,0.88)
Pre-pupa				80	10	0
Pupa				80	10	0
Adult				1 Female 1 Male	3 Females 6 Males	7 Females 3 Males

* cumulative percentage mortality (n=10)
\# mean longevity in days and S.D. for thrips that suvived to the next instar

TABLE 3.2: MORTALITY AND MEAN DEVELOPMENT TIME OF THE NEW ZEALAND FLOWER THRIPS REARED ON DIETS OF PLANT TISSUES AT 20°C.

Treatment		1 Pollen	2 Stamen Filament	3 Fruit
1st instar		0*	0	15
	F	2.0 (0.0,8)#	3.6 (0.5,5)	3.5 (0.5,2)
	M	2.0 (0.0,11)	2.9 (0.22,14)	3.3 (0.42,10)
2nd instar		5	0	35
	F	3.9 (0.35,8)	3.6 (0.4,5)	6.0 (1.0,2)
	M	3.2 (0.12,11)	3.7 (0.16,14)	4.5 (0.31,10)
Pre-pupae		5	0	35
	F	1.1 (0.13,8)	1.6 (0.25,5)	1.5 (0.5,2)
	M	1.3 (0.14,11)	1.4 (0.14,14)	1.3 (0.15,10)
Pupae		5	5	40
	F	3.3 (0.16,8)	2.8 (0.2,5)	3.0 (0.0,2)
	M	3.1 (0.16,11)	2.7 (0.13,14)	2.9 (0.23,10)
Total Dev't	F	10.3 (0.25,8)	11.6 (0.25,5)	14.0 (1.0,2)
	M	9.5 (0.16,11)	10.7 (0.19,14)	12.3 (0.54,10)

* cumulative percentage mortality for both sexes (n=20)
\# mean longevity in days (S.D., n) excluding instars that did not develop to adult

3.2.3 EFFECT OF POLLEN TYPE

Larvae developed to adults with all species of pollen. Mortality was lowest with *Hebe* (6.7%), followed by gorse (16.7%), flax (20%) and Iceland poppy (26.7%). Development times for immature stages (excluding egg) are given in Table 3.3. For females and males values of total development (larvae to adult) were not significantly different except for males supplied with flax pollen. Total development of males on flax pollen took longer than *Hebe* (t=2.47, p=0.031, df=11.0) and gorse (t=3.02, p=0.0.016, df=8.0). Sample sizes were small. All adult females from which the larvae developed were *T. obscuratus*.

3.3 DEVELOPMENT AT CONSTANT TEMPERATURES

Mean development time and adult lifespan are given in Table 3.4 for all stages of both sexes of *T. obscuratus* at seven constant temperatures. Only those eggs and larvae that developed to adults and were identified were included. Development time for egg to adult ranged from 10 days at 27°C (male) to 50 days at 10°C (female). Except for egg development, immature female stages generally took longer to develop than males. Development time from egg to adult was significantly longer for females than for males at 10°C (t=6.55, p=0.023, df=2.2), 15°C (t=5.4, p=0.00001, df=13.0), 19°C (t=3.98, p=0.0003, df=34.3), 20°C (t=3.54, p=0.012, df=6.6) and 25°C (t=5.45, p=0.012, df=3.8). Development was longer for females, but not significantly so, at 23 and 27°C. Female adults lived longer than males on average at all temperatures where lifespan was recorded, although there was large variation between individuals. At constant temperatures, greatest mortality occurred during the egg stage and at 1st instar (Table 3.5). Mortality of prepupal and pupal stages was low.

Development rate showed a linear relationship with temperature between 10 and 27°C for all development stages of each sex (Fig. 3.7). Values of the coefficient of determination were all above 0.78 except for male pupae. The lower thresholds of development and thermal constants are given in Table 3.6. The results gave little indication as to the upper threshold, as development was still continuing proportionally at 27°C. However it is probably close to 30°C, as egg and larval mortality was very high when attempts were made to rear thrips at this temperature.

3.4 REPRODUCTION

All females introduced to males soon copulated. Time to initiate copulation ranged from 9 sec. to 2 min. 23 sec. (av.1 min. 23 sec.); time in copula ranged from 1 min. 10 sec. to 1 min. 33 sec. (av. 1 min 23 sec.).

Female thrips that had not mated all produced male offspring (treatment 2) at both week 1 and 3 after maturity whereas some females that had been mated (treatment 1) produced females as well as males (Table 3.7). Adult lifespan averaged about four weeks with no significant difference between treatments (t=-0.44, p=0.67, df=8.4). Fecundity ranged from 57 eggs for a female that lived for two weeks to 298 eggs for a female that lived for seven weeks. Two individuals laid no eggs, and they were not considered in mean estimates of fecundity (Table 3.7). The abdomens of these sterile thrips were full of parasitic

TABLE 3.3: MORTALITY AND MEAN DEVELOPMENT TIME OF THE N.Z. FLOWER THRIPS REARED ON DIFFERENT POLLEN AT 20°C.

Treatment		Gorse		Iceland Poppy		Flax		*Hebe* sp.	
1st instar			0.0*		6.7		6.7		0.0
	F	2.1	(0.38, 7)#	2.0	(0.0, 5)	2.6	(0.53, 7)	2.0	(0.0, 7)
	M	2.2	(0.45, 5)	2.1	(0.38, 7)	2.6	(0.53, 7)	2.0	(0.0, 7)
2nd instar			0.0		20.0		6.7		6.7
	F	4.3	(1.38, 7)	5.6	(1.52, 5)	4.6	(1.27, 7)	3.7	(1.5, 7)
	M	3.4	(0.89, 5)	3.4	(0.79, 7)	3.4	(0.53, 7)	3.3	(0.49, 7)
Prepupae			0.0		20.0		13.3		6.7
	F	1.3	(0.49, 7)	1.2	(0.45, 5)	1.4	(0.53, 7)	1.0	(0.0, 7)
	M	1.0	(0.0, 5)	1.3	(0.49, 7)	1.3	(0.52, 6)	1.1	(0.38, 7)
Pupae			16.7		26.7		20.0		6.7
	F	3.0	(0.0, 6)	3.3	(0.5, 4)	3.0	(0.0, 6)	3.0	(0.0, 7)
	M	2.5	(1.0, 4)	2.7	(0.49, 7)	3.0	(0.0, 6)	2.3	(0.95, 7)
Total Development	F	10.0	(1.1, 6)	11.3	(1.26, 4)	11.2	(0.98, 6)	9.7	(1.5, 7)
	M	8.5	(1.0, 4)	9.3	(0.76, 7)	10.2	(0.75, 6)	8.7	(1.25, 7)

* cumulative percentage mortality

\# mean development time in days (S.D., n) excluding instars that did not develop to prepupae

TABLE 3.4 : DEVELOPMENT TIME (DAYS) AND ADULT LIFESPAN (WEEKS) OF THE N.Z. FLOWER THRIPS AT CONSTANT TEMPERATURES.

Temperature		10°C		15°C		19°C		20°C		23°C		25°C		27°C	
Egg	F	12.0	(0.0, 2)*	5.1	(0.35, 8)	5.1	(0.30, 11)	4.0	(0.0, 4)	3.2	(0.37, 19)	3.0	(0.0, 3)	3.0	(0.0, 3)
	M	13.0	(1.41, 11)	5.8	(0.63, 10)	5.4	(0.59, 38)	4.3	(0.49, 7)	3.7	(0.48, 16)	3.1	(0.32, 19)	3.0	(0.0, 9)
1st instar	F	6.8	(0.5, 4)	3.3	(0.46, 8)	2.9	(0.30, 11)	2.3	(0.50, 4)	2.0	(0.23, 19)	2.0	(0.0, 3)	1.3	(0.58, 3)
	M	6.1	(0.70, 11)	2.9	(0.32, 10)	2.8	(0.55, 36)	2.0	(0.0, 7)	2.0	(0.33, 29)	2.0	(0.37, 16)	1.7	(0.47, 11)
2nd instar	F	15.5	(1.91, 4)	6.3	(0.71, 8)	3.7	(0.65, 11)	3.5	(0.58, 4)	2.6	(0.60, 19)	4.0	(0.0, 3)	2.7	(0.58, 3)
	M	10.8	(1.28, 8)	4.4	(0.52, 10)	3.4	(0.65, 35)	3.0	(0.63, 6)	2.2	(0.47, 29)	2.3	(0.48, 16)	2.3	(0.47, 11)
Prepupae	F	3.5	(0.71, 2)	2.3	(0.46, 8)	1.6	(0.50, 11)	1.8	(0.50, 4)	1.2	(0.42, 19)	1.0	(0.0, 3)	1.0	(0.0, 3)
	M	4.6	(0.79, 7)	2.4	(0.52, 10)	1.5	(0.51, 38)	1.0	(0.0, 6)	1.1	(0.40, 30)	0.9	(0.32, 19)	0.9	(0.29, 12)
Pupae	F	10.5	(0.71, 2)	4.8	(0.46, 8)	3.9	(0.3, 11)	3.3	(0.58, 4)	2.5	(0.51, 19)	2.7	(0.58, 3)	2.3	(0.58, 3)
	M	8.8	(1.32, 10)	4.0	(0.82, 10)	3.2	(0.86, 39)	2.4	(0.74, 7)	2.4	(0.62, 30)	2.1	(0.66, 19)	2.2	(0.58, 12)
Egg to adult	F	50.0	(1.41, 2)	21.6	(0.92, 8)	17.3	(0.65, 11)	14.3	(0.58, 3)	11.5	(0.84, 19)	12.7	(0.58, 3)	10.3	(0.58, 3)
	M	42.0	(2.32, 11)	19.5	(0.71, 10)	16.1	(1.30, 38)	12.5	(0.98, 7)	11.4	(0.81, 16)	10.5	(0.90, 19)	10.0	(0.87, 9)
Adult to oviposition		16.5	(3.3, 4)	10.4	(5.26, 8)	7.3	(1.9, 11)	6.3	(2.31, 3)	5.0	(2.32, 19)	4.7	(0.58, 3)	4.0	(0.0, 1)
Adult (lifespan)	F	34.4	(2.87, 4)	17.4	(2.39, 8)			7.3	(3.59, 4)			3.0	(1.0, 3)		
	M	25.7	(14.0,10)	11.5	(4.4, 10)			5.7	(4.41, 6)			1.6	(1.29, 11)		

* (S.D., n)

TABLE 3.5: MORTALITY OF THE N.Z. FLOWER THRIPS REARED IN THE LABORATORY.

	Temperature °C							
Experiment	10^{x}	15^{x}	20^{x}	25^{x}	$20^{a,x}$	$20^{b,y}$	$20^{c,x}$	$20^{d,z}$
Egg	73.3*	47.2	80.9	31.9	32.1	6.2	43.1	12.5
1st instar	1.7	2.8	6.0	19.1	-	-	-	)
2nd instar	1.7	0	0	2.1	-	-	-	) 16.0
Prepupae	1.7	0	0	0	-	-	-	)
Pupae	0	0	0	0	-	-	-	)
Initial no.	60	36	83	47	440	357	281	136

* Percentage mortality for each life stage
a Oviposition Experiment 2.1.1
b Oviposition Experiment 2.1.2
c Oviposition Experiment 2.1.3
d Reproduction Experiment 2.4

x Parafilm removed immediately after oviposition
y Parafilm not removed
z Parafilm removed at 'red eye' stage

TABLE 3.6: LOWER THRESHOLD TEMPERATURES OF DEVELOPMENT AND THERMAL CONSTANTS FOR MALE AND FEMALE N.Z. FLOWER THRIPS

Stage	Sex	Lower Threshold (°C)	Thermal Constant K (Day-degrees)*
Egg	F	4.4	61.7
	M	5.8	62.9
Larvae	F	6.0	82.6
	M	4.2	84.7
Pupae	F	6.1	64.5
	M	5.2	59.2
Adult	F	5.6	211.4
	M	5.0	211.9
Egg-egg		6.3	283.3

* K = 1/m for y = mx+c of development line (Campbell *et al.* 1974).

FIGURE 3.7: DEVELOPMENT RATES FOR LIFE STAGES OF THE N.Z. FLOWER THRIPS UNDER CONSTANT TEMPERATURES.

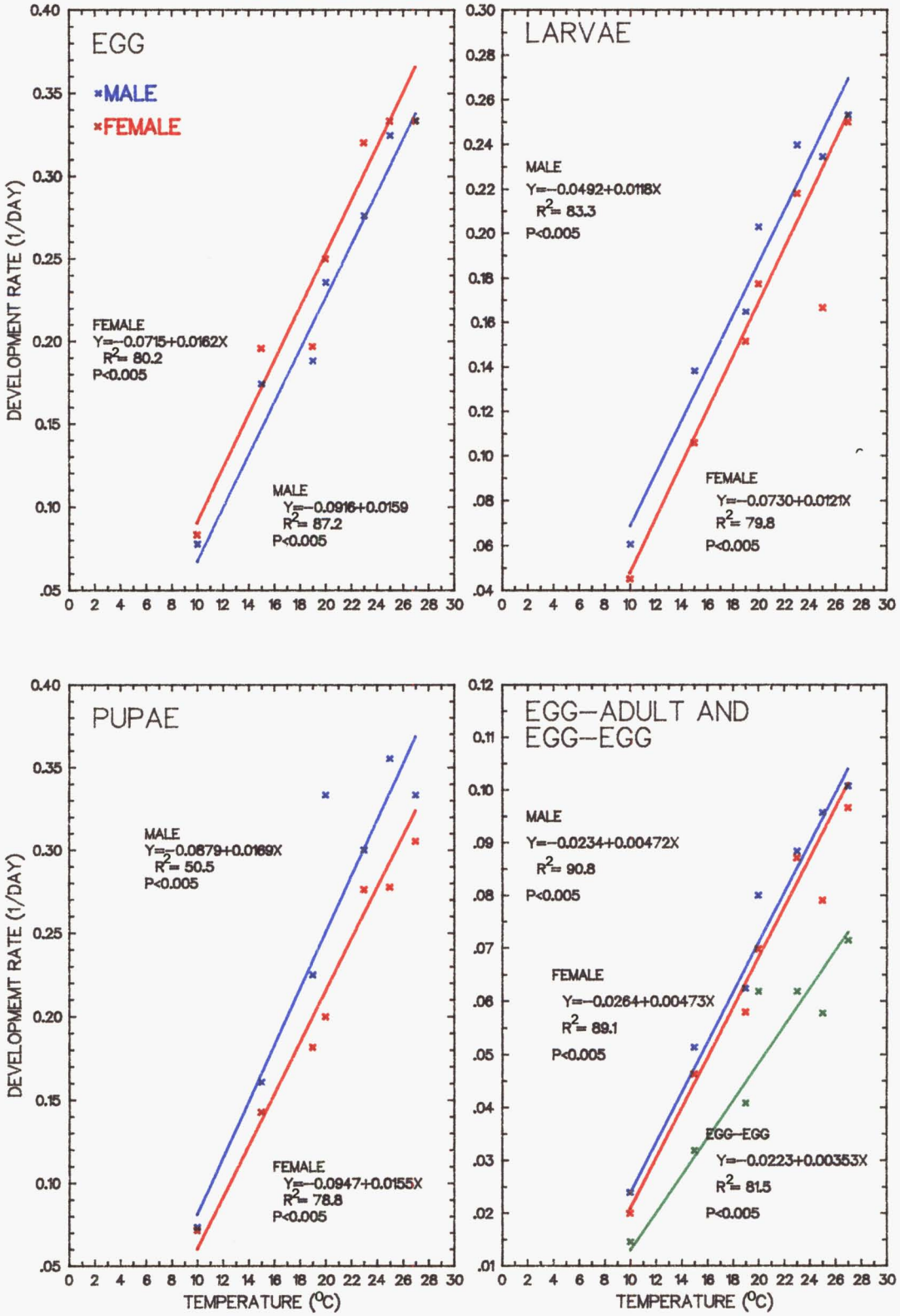


TABLE 3.7: FECUNDITY, LIFESPAN AND SEX OF (1) MATED AND (2) UNMATED FEMALE N.Z. FLOWER THRIPS.

(1) MATED THRIPS

			Weeks After Adult Eclosion									
thrips	1[?]		2	3		4	5	6	7	8	total eggs	total week
1	6[#]	(5M)[@]	28	2		13	5[d]	-	-	-	54	4
2	5	(5F)	46	43	(2M)	48	56	50	50	0[d]	298	7
3	7	(5F,1M)	35	24[d]		-	-	-	-	-	66	2
4	10	(7M)	62	60	(9M)	76	53	36[d]	-	-	297	5
5	11	(8F,2M)	46	43	(2F,2M)	0[d]	-	-	-		100	3
6	8	(8M)	es	-		-	-	-	-	-	-	-
mean[*]			43.4	37		45.7	54.5	50	50		163	4.2
n			5	4		3	2	1	1		5	5
S.D.			11.6	21.4		25.8	1.5	-	-		110.9	1.7
total		(18F,23M)			(2F,13M)							

(2) UNMATED THRIPS

			Weeks After Adult Eclosion									
thrips	1[?]		2	3		4	5	6	7	8	total eggs	total week
1	7	(7M)	54	47[d]		-	-	-	-	-	108	2
2	13	(8M)	51	62	(4M)	54	41	25[d]	-	-	245	5
3	14	(13M)	53	38	(1M)	6[d]	-	-	-	-	111	3
4	12	(3M)	45	0[d]		-	-	-	-	-	57	2
5	8	(6M)	41	31	(2M)	43	8[d]	-	-	-	131	4
6[p]	0		0	0[d]		-	-	-	-	-	0	3
7[p]	0		0	0		0	0	0	0	0[d]	0	7
mean[*]			48.8	43.7		48.5	41				130.4	3.7
n			5	3		2	1				5	7
S.D.			5.0	13.3		5.5	-				62.3	1.7
total		(37M)			(7M)							

? eggs only counted on last day of week 1
\# no. eggs per thrips per week
@ sex off offspring of eggs laid on last day of week
d dead
es escaped
* not including dead, parasitised or escaped thrips
p parasitised by nematodes

nematodes (see Plate 5). Mean fecundity was 130.4 eggs per lifespan for unmated thrips and 163 eggs for mated thrips. There was no significant difference in fecundity between treatments (t=-0.51, p=0.63, df=6.3). Oviposition of females in both treatments remained at a similar level throughout the lifetime of the thrips. Seventy-three percent of eggs developed through to adult. All thrips were identified as *T. obscuratus*.

4 DISCUSSION

Temperature and food were both important influences on the life history of *T. obscuratus* in laboratory conditions. Temperature is well-known as one of the most important environmental factors influencing insects (Wigglesworth 1972). A general relationship between temperature and insect activity or survival is often recognised. Above a lower temperature threshold, insect metabolism and activity increase with increasing temperature up to a point and then decrease with further temperature increase until the upper lethal point is reached (Chiang 1971). A linear relationship between temperature and rate is sometimes formalised to determine the lower temperature threshold of development (Teulon and Penman 1987) and egg production (Lewis 1973).

Growth, development and reproduction of insects are directly dependent on the quantity and quality of food ingested (Hagen *et al.* 1984). The study of the food habits of flower-associated insects, including thrips, has established the importance of pollen as insect food (Grinfel'd 1959, Kirk 1985). Pollen exceeds all other parts of the plant in food value (Grinfel'd 1959) and it is likely that the high protein content of pollen (Hagen *et al.* 1984) is especially significant (Andrewartha 1935). Pollen feeding among thrips is widespread, although it is virtually unknown in other sucking insects (Grinfel'd 1959, Kirk 1984a).

4.1 OVIPOSITION

Pollen is an important requirement of egg production in several insect species (Gilbert 1972, Pesho and van Houten 1982) including some thrips. Insects with a high-protein diet are known to produce many more eggs than those that take little (Englemann 1984). The presence of pollen was a significant factor in continuing high levels of oviposition with *Thrips imaginis* (Andrewartha 1935), *Frankliniella intosa* (Murai and Ishii 1982) and *Thrips fuscipennis* (Kirk 1985). Pollen was also important to *T. obscuratus*. With the removal of pollen from rearing cages containing *T. obscuratus* females, oviposition soon declined and within two days had reached levels much lower than that of females supplied with pollen. When thrips were resupplied with pollen, oviposition resumed its previous high levels.

T. obscuratus breeds in flowers of many plant species (see Chapter IV) and therefore pollen type is unlikely to be an important factor limiting ovipositon. This was not examined, although both Iceland poppy and rose pollen facilitated oviposition in the laboratory. Adult *T. obscuratus* females have been reported feeding on male kiwifruit (*Actinidia deliciosa*) pollen in the laboratory (Kirk 1987b). Another generalist flower thrips, *Thrips fuscipennis*, laid similar numbers of eggs with different pollens. In

comparison, flower thrips with more specific host ranges, *Kakothrips pisivorous* and *Ceratothrips ericae*, laid significantly more eggs with pollen from their hosts than with pollens of other plants (Kirk 1985). Thus feeding specificities in thrips are reflected in oviposition rates (Kirk 1985).

Oviposition rate decreased with lower temperatures in *Thrips imaginis* (Andrewartha 1935) and *Heliothrips haemorrhoidalis* (Rivnay 1935), as it did with *T. obscuratus*. The calculated lower threshold of oviposition for *T. obscuratus* was close to 7°C. This was a higher temperature threshold than those established for development (Table 3.6), but means that eggs were laid only at temperatures at which development could proceed immediately.

Oviposition rates varied in the different experiments due to different conditions, but at 20°C the average oviposition rates of *T. obscuratus* were consistent with oviposition rates of other thrips (Lewis 1973). Like females of *Thrips imaginis* (Andrewartha 1935) and *Heliothrips haemorrhoidalis* (Rivnay 1935), the fecundity of *T. obscuratus* remained at about the same level throughout the lifetime of the adult. Fecundity was not influenced by mating. Total fecundity for *T. obscuratus* was therefore restricted by adult lifespan and diet at a given temperature. Total egg production may not be adversely affected with lower temperatures, as lifespan increased proportionately at lower temperatures. Up to 298 eggs were laid by a single female (av. 130-160). This was consistent with the fecundity of other thrips (Lewis 1973). Sterile females were clearly parasitised by nematodes. Parasitism will be discussed further in Chapter IV.

4.2 HATCHING

Mortality of *T. obscuratus* eggs in laboratory rearing was variable but usually high (Table 3.5). In rearing cages where eggs were exposed immediately by removal of the upper parafilm membrane, egg mortality ranged from 30 to 81%. Eggs are normally laid within plant tissue (see Chapter IV), and exposing them to air, even in a moist container, did not provide ideal conditions for their development. Egg mortality was drastically reduced to about 6% if the upper layer of the double parafilm membrane was left intact until eclosion (Table 3.5), but newly-hatched larvae were trapped between the membranes and a significant number drowned in the nutrient medium. If the upper layer of the double membrane was removed at the 'red eye' stage of egg development, egg mortality was reduced to about 12% (Table 3.5) and newly-hatched larvae did not drown. This compares favourably with hatch rates of 58 and 62% for *Frankliniella intonsa* and *Thrips hawaiiensis* respectively using the method of Murai and Ishii (1982). The effect of temperature on egg mortality was masked by the high mortality of larvae.

4.3 LARVAL DEVELOPMENT

T. obscuratus sucessfully completed larval development at 20°C on plant material including pollen, stamen filaments and peach fruit, but not on sucrose or apple/peach juice alone. Nutrient media by themselves were sufficient for larval survival for a certain time, usually longer than the normal instar length, but failed to supply the requirements for ecdysis. Larvae supplied with only water soon died. Pollen ensured the fastest development of larvae as well as least mortality, compared to stamen filaments

and peach fruit (Table 3.2). Pollen was also important in the larval diets of *Frankliniella intosa* and *Thrips hawaiiensis*. Although development was fastest on tomato fruit for *Frankliniella intosa*, mortality was lowest on a diet of honey solution and pollen. Diets of honey or water did not allow development beyond first instar, although with honey diets the length of the larval instar was extended (Murai and Ishii 1982). Rate of larval development was significantly improved with the addition of cotton pollen to the diet of *Frankliniella occidentalis*, even though larvae were not commonly found in the short-lived flowers (Trichilo and Leigh 1988).

Some *T. obscuratus* larvae supplied with pollen and water developed to adults, but the mortality was high. Similar results were obtained with diets of pollen and water for *Frankliniella intosa* and *Thrips hawaiiensis* (Murai and Ishii 1982). This suggests either that pollen does not completely fulfil the requirements for larval development, or insufficient pollen was supplied for complete development in both studies. In nature pollen is seldom found without some other carbohydrate source (e.g., floral tissue or nectar), so this point is of academic interest only; nevertheless it is a constraint in the laboratory rearing of thrips. Larval development time and mortality of the generalist flower thrips, *Frankliniella intosa*, were similar on diets of several species of pollen (Murai and Ishii 1982). There are no similar experiments with thrips of a limited host range. *T. obscuratus* is known to have a wide host range (Chapter IV), and larval development time and mortality were very similar on both endemic (flax, *Hebe*) and introduced (gorse, poppy) pollens. The generalist feeding behaviour of *T. obscuratus* has allowed it to enlarge its host range remarkably with the introduction of flowering plants from overseas.

T. obscuratus larvae are sometimes found on fruit and leaves but are most common on flowers (see Chapter IV). Although they can reach maturity on plant tissues in the absence of pollen, development in terms of time and survival is best with pollen. Thus larvae profit by inhabiting flowers. Only on ephemeral flowers are larvae at risk if there is not sufficient time to complete development (Trichilo and Leigh 1988). Adult *T. obscuratus* are also commonly found on flowers, where pollen is available to maximise egg production and possibly encourages oviposition in the vicinity of pollen for future larval survival.

Arrhenotokous parthenogenetic reproduction is exhibited by *T. obscuratus*. All 45 offspring of virgin females were males, whereas offspring of mated females were both male and female. Arrhenotoky is common among other thrips (Bailey 1933, Munger 1942, Zawirska 1963).

Expression of these biological features is dependent on temperature. In laboratory rearing of *T. obscuratus* at constant temperatures between 10 and 27^{o}C, there were strong linear relationships between development rate and temperature for most life stages. As these temperatures are near the limits of those commonly found in the field throughout the growing season in Canterbury, the calculated lower threshold temperatures may be used with some confidence (Gordon 1984). Validation of lower thresholds derived from laboratory studies should be attempted with some reference to field data (Teulon and Penman 1987) but the continuous and overlapping generations of *T. obscuratus* throughout the season makes this very difficult.

Mortality of larvae and pupae was low at all temperatures except for first instar at 25^{o}C. Where mortality is high at low temperatures development rates may be influenced by the selection of cold-hardy individuals (Campbell *et al.* 1974), but this was not the case with these results. The increase of first instar

mortality at 25°C may be an indication that the upper threshold of development was close. At 30°C larvae died soon after hatching. Mortality of first instar larvae which was higher than that of other instars at temperatures other than 25°C may have been due to handling during the transfer of newly-emerged larvae into rearing cages.

Mortality of the prepupal and pupal stages was low, even though conditions in the rearing cages were unlike those found in the humid conditions of leaf litter and soil where *T. obscuratus* has been found to pupate (see Chapter IV). When rearing cages were not placed inside humid plastic boxes, larvae developed normally until the prepupal stage and then died. Pupation continued normally when rearing cages were placed in humid plastic boxes. Relative humidity was measured at 100% within these boxes at several temperatures. Rivnay (1935) found that a relative humidity of 75% was necessary for pupation of *Heliothrips haemorrhoidalis*. Survival of larvae to adults using the method described in this chapter was similar to the results achieved by Murai and Ishii (1982) and Wang and Chu (1986).

Pupation in rearing cages in the laboratory continued under intense light. Light would normally be of low intensity in pupation sites in the ground. This may indicate that the avoidance of light by pupae of some species (Loan and Holdaway 1955) is a preadaptation for finding humid conditions in the soil. Pupation of *T. obscuratus* sometimes occurs, where humidity is sufficient, in places other than the ground. Pupal stages have been found in caged flower heads by Mound and Walker (1982) and McLaren (1985). Therefore light by itself does not appear to limit pupation. Pupation in the ground is presumably an adaptation so that development can continue when the flower has died.

4.4 ADULT LIFESPAN

Adult lifespan increased with decreasing temperature and females tended to live longer than males (Table 3.4). It is likely that thrips males are much shorter-lived than females (Bournier 1983). There was little difference in lifespan between mated and unmated females. Parasitism by nematodes does not appear to influence adult longevity, as one sterile female infested with nematodes lived as long as any other thrips (Table 3.7). The little information published indicates that the lifespan of *T. obscuratus* is of comparable length to that of other thrips (Lewis 1973). Longevity at low temperatures (up to 34 weeks at 10°C) indicated that adult thrips can overwinter. *T. obscuratus* females and males have been found throughout winter in Canterbury. There was no evidence for any obligative or facultative diapause.

5 SUMMARY

The aims of this chapter were to establish the factors important in oviposition, egg and larval development, reproduction and adult longevity for *T. obscuratus*. The following were the major results:

(a) A simple method for laboratory rearing was developed to facilitate these studies.

(b) Pollen was necessary for sustained egg production.

(c) The rate of egg production increased with increasing temperature between 10 and 25°C. A lower threshold temperature for egg production was calculated at 6.9°C.

(d) Egg production remained at a similar level throughout adult life and was not influenced by mating. Up to 298 eggs were laid by a single female (av. 130-160).

(e) *T. obscuratus* is arrhenotokous.

(f) At 20°C diets of pollen and sucrose or fruit juice were most succesful for larval development though pollen could be substituted for by stamen filaments or peach fruit. Type of pollen did not influence development time or larval mortality.

(g) Development time for individual instars and for total development decreased with increasing temperature between 10 and 27°C. Total development ranged from 50 days at 10°C for females to 10 days at 27°C for males. Female development took longer at a given temperature than male development. The relationship between temperature and development rate was expressed as a straight line. Lower thresholds of development of between 4.2 and 6.3°C were established for different developmental stages by regression.

(h) Adult lifespan increased with decreasing temperature between 10 and 25°C. Females lived longer than males and their lifespan was not influenced by mating. At 10 and 25°C females lived for an average of 34 and 3 weeks respectively. Adult females parasitised by nematodes were sterile but their lifespan did not appear to be reduced.

These data help to explain the life history of *T. obscuratus* in the field so that strategies can be devised to control the pest. Specific applications of these data are not listed here but will be referred to in the appropriate chapters that follow.

CHAPTER IV

ASPECTS OF THE BIOLOGY AND ECOLOGY OF THE NEW ZEALAND FLOWER THRIPS

1 INTRODUCTION

The next three chapters concern the biology and ecology of the New Zealand flower thrips under field conditions. In this chapter several aspects will be investigated, including the determination of host plants, thrips infestation and phenology on stonefruit flowers, flight thresholds, diurnal activity and the natural enemies of *T. obscuratus*. Thrips infestation of the fruit of stonefruit and the seasonal abundance of *T. obscuratus* will be examined in Chapters V and VI respectively.

T. obscuratus is polyphagous, being found on a wide range of plants (Mound and Walker 1982). Nevertheless, the most recent host list of Spiller and Wise (1982) is out of date and only includes records of adults. There are other scattered host plant references, again mostly of adults. The establishment of hosts, especially breeding hosts, is important as it suggests factors that could be involved in host specificity and reveals sources of crop infestation (Kirk 1987a).

The timing and extent of thrips infestation during the development of stonefruit flowers is an important consideration in pest management. McLaren (1980-1987) has observed thrips on stonefruit during the flowering period in Central Otago, New Zealand, and related the presence of adults between full bloom and petal fall to be the main cause of fruit damage. These observations conflict with those of researchers overseas, who consider that most damage is caused by the larvae from petal fall onwards (e.g., Bournier 1970, La Rue *et al.* 1972, Cravedi and Molinari 1984). However, there have been few quantitative studies of any thrips species on stonefruit flowers (e.g., Cravedi *et al.* 1983, Cravedi and Molinari 1984), and none that has established the degree of larval infestation. A knowledge of the relative importance of adult and larval infestation and phenology on stonefruit flowers is necessary to time control measures for maximum effect.

The pupal stages of thrips are sometimes the target of control measures. Flooding and cultivation have been used to kill pupae in the soil (Lewis 1973). With polyphagous flower thrips, control by these methods is impractical as pupation may take place beneath many widely-spaced hosts. Nevertheless, determination of the pupation sites of *T. obscuratus* is necessary for a full understanding of the thrips life cycle and may give some insight into natural population regulation.

In Central Otago, sampling stonefruit trees for thrips was productive only between 11 a.m. and 3 p.m. during October and November. At other times thrips were absent (McLaren unpubl.). Variations of this sort in thrips activity may also be a constraint on thrips sampling in Canterbury and important for the timing of control, especially insecticides. The diurnal fluctuation of thrips activity on flowers may be related to temperature; thrips may move on to stonefruit trees only when their flight take-off threshold is

reached. However, there is confusion as to what the flight take-off thresholds for *T. obscuratus* are (McLaren 1981, 1985). Confirmation of the diurnal activity of thrips on stonefruit in Canterbury and clarification of the flight take-off thresholds is therefore needed.

No parasites and few predators have been reported in the literature for *T. obscuratus* in New Zealand. Although biological control has not been a significant method for the control of thrips generally, predators and parasites may contribute to a worthwhile reduction in thrips pest populations (Bournier 1983). Evidence of parasitism by nematodes was found late in the course of this work in laboratory studies of *T. obscuratus* (Chapter III). Thrips from other sources (e.g., water traps and fruit samples) were also found to be infested by nematodes. These parasites and any other natural enemies may be important in the natural regulation and biological control of *T. obscuratus*.

The primary aims of the research in this chapter were therefore:

- to establish the hosts, especially breeding host plants, of *T. obscuratus*;
- to investigate the level of infestation, phenology and diurnal activity of thrips on stonefruit flowers;
- to establish flight take-off thresholds, and
- the occurence of the natural enemies of *T. obscuratus*.

2 MATERIALS AND METHODS

2.1 HOSTS

A detailed search of the literature was undertaken to establish published host plants for *T. obscuratus*. Unpublished host records were also obtained from a number of entomological research and quarantine centres in New Zealand.

Plants, especially flowers, were investigated for the presence of thrips adults and larvae around Canterbury, New Zealand, from December 1984 to February 1988. Most of the plants were on the Lincoln College campus or in the grounds of the Christchurch City Botanical Gardens. Thrips collected in the field were placed in either a plastic bag or a collection cylinder (see Appendix 3). They were removed from the plant material with a fine camelhair brush or extracted by heat. Some live larvae were placed in rearing cages (5 per cage) supplied with pollen and a nutrient medium to rear them to adults (see Chapter III). To prepare dead adult thrips for identification they were mounted on microscope slides with polyvinyl alcohol (PVA) beneath a coverslip and left for at least 24 hours (Walker and Crosby 1979). Thrips were identified according to Mound and Walker (1982, 1986). This was the procedure for mounting and identification of thrips throughout the work reported in this chapter.

A host plant list was compiled indicating plants on which *T. obscuratus* adults and larvae were found (see Appendix 6). Sample date (month), location of find (Crosby *et al.* 1976), sex and maturity of the thrips and sources of the information were included. A separate list was compiled for the larvae of *T. obscuratus* reared to adults. This also included the flower colour of the host. Flower colour was

established from records taken on the sample date or from Allan (1961), Moore and Edgar (1970), and Eagle (1975, 1982) for endemic plants and Bailey and Bailey (1976) and Healy and Edgar (1980) for introduced plants.

Plant families and genera were grouped according to Hutchinson (1973). Species and common names were obtained from Allan (1961), Moore and Edgar (1970) and Conner and Edgar (1987), for indigenous plants, from Lambrechtsen (1975) for introduced grasses and from Healey (1984) for weeds. Any hosts not found in these references were grouped according to Bailey and Bailey (1976).

2.2 PHENOLOGY ON STONEFRUIT FLOWERS

Nectarine and peach (*Prunus persica*) flowers were sampled for thrips from unsprayed trees at different stages of flower development.

NECTARINE, 1986. Flowers and young fruit were sampled between 90% pink (10-9-86) and 90% shuck fall (31-10-86) from four to ten day intervals from a single mature nectarine tree (var. unknown) situated on the Lincoln College campus (see Appendix 4). At each sample 50 flowers (40 on 14/10 and 31/10) were picked from the tree below 2.5 m, and 10 placed in each of 5 collection cylinders (4 on 14/10 and 31/10). Thrips were extracted from flowers with heat using the method described in Appendix 3. Adult thrips were mounted and identified. At about 80% full bloom (23/9) all the flowers on the tree were counted.

NECTARINE AND PEACH, 1987. Flowers and young fruit were sampled between 90% pink (3-9-87) and 90% shuck fall (3-11-87) from four to nine day intervals from four to five young nectarine and six to seven young peach trees situated in a mixed deciduous tree variety block in the Organic Area of the Lincoln College Horticultural Research Area (see Appendix 5). Each tree was of a different variety (see Appendix 5) with slightly different flowering dates, although an effort was made to keep the phenological expression of the flowers the same for a given sample date.

At each sample 10 flowers were picked from below 2.0 m on each tree and placed in a collection cylinder. Thrips were extracted from flowers with heat using the method described in Appendix 3. Adult thrips were mounted and identified.

At petal fall (1-10-87) 25 live larvae were extracted by hand from flowers of tree number 2 (nectarine) and tree number 7 (peach). These were transferred to rearing cages (see Chapter III), reared to adults, mounted and identified.

Six water traps were placed at regular intervals throughout the block on 10/9/87 to monitor thrips flights. Water traps were white 2-litre ice-cream containers (170 x 170 x 85 mm) (Probit Industries Ltd. Auckland) placed on 1.7 m wooden poles positioned between trees (see Plate 6). The traps were constructed to allow easy removal from the poles and painted with several coats of white paint (White Superseal, Dulux N.Z. Ltd). Each trap contained about one litre of water, a few drops of formaldehyde to prevent algal and fungal growth, and detergent to facilitate thrips sinking in the water. White-painted netting (mesh size 20 x 20mm) was used to prevent the entry of leaves and birds. Thrips were removed weekly and the fluids renewed. Trapping ceased on 22/10/87. Adult thrips were mounted and identified.

PLATE 5. FEMALE NEW ZEALAND FLOWER THRIPS' ABDOMEN INFESTED WITH NEMATODES (x160 APPROX.).

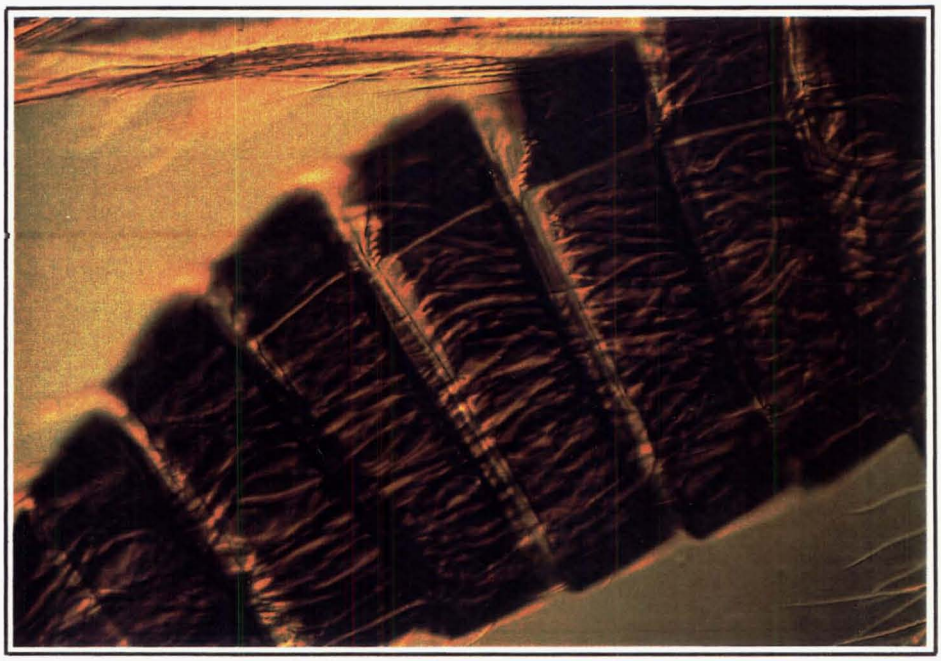
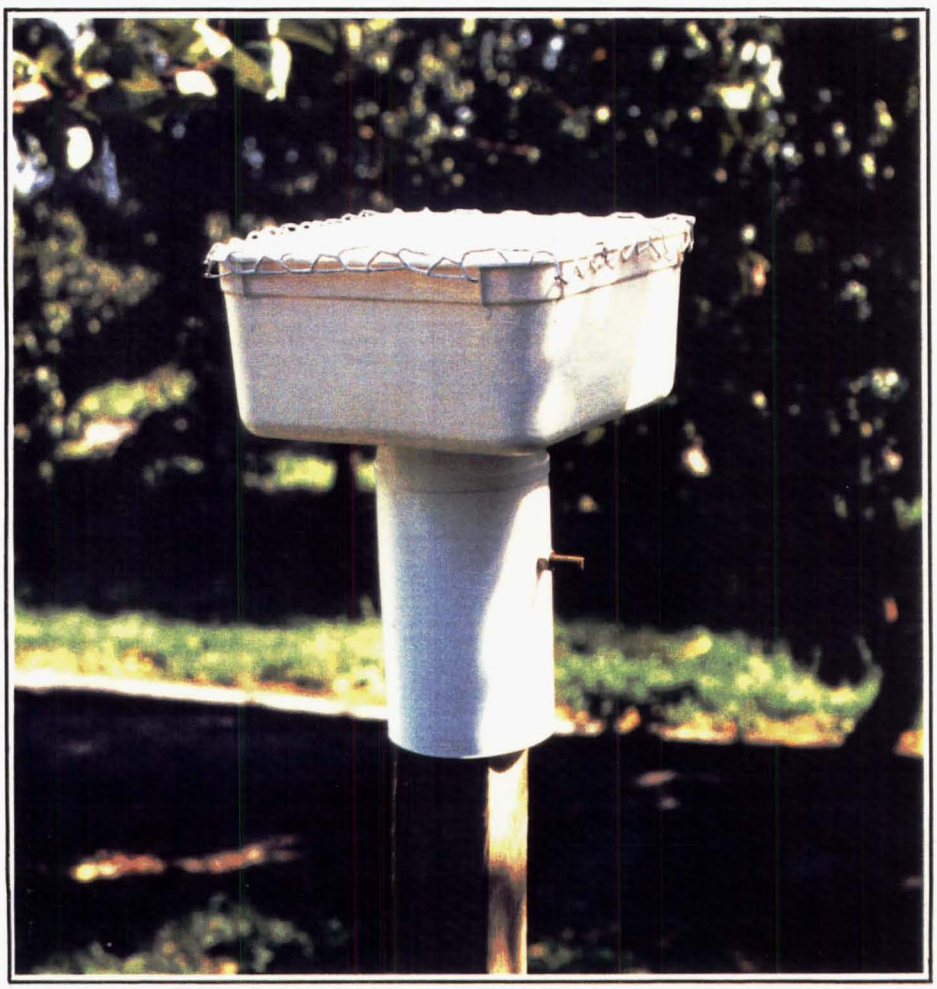


PLATE 6. WATER TRAP FOR MONITORING THRIPS FLIGHTS.



For both years maximum and minimum daily temperatures were obtained from the nearby Lincoln College Meteorological Station (Appendix 4).

2.3 PUPATION

Leaf litter was collected from beneath a cabbage tree (*Cordyline australis* (Forst f.)) situated in the Lincoln College formal garden (see Appendix 4) on 28 November 1985. Four days before the sample the flowers of this tree had been found to be heavily infested with *T. obscuratus* adult females, males and larvae. The litter was collected in plastic bags, and in the laboratory placed on a tray and examined for the presence of thrips larvae, prepupae and pupae. Live larvae, prepupae and pupae were transferred to rearing cages (see Chapter III), reared to adults, mounted and identified.

A further sample of leaf litter and soil was made beneath another flowering cabbage tree situated on the Lincoln College campus on 19 December 1985. Six cylindrical bores (dia. 100 mm) were made in a concentric circle about one metre from the tree. Litter, topsoil (0-20 mm) and soil (40-60mm) for each bore were separated and each was placed in Berlese-Tullgren funnel for 19 days. Emerging adult thrips were caught in alcohol (70%) beneath the funnel and adults were mounted and identified.

2.4 FLIGHT TAKE-OFF THRESHOLDS.

Flight take-off thresholds for thrips have been determined in the field by plotting hourly catches in suction traps or daily sticky trap catches with maximum hourly or daily temperatures respectively (Lewis 1973, McLaren 1985). An extension of this idea is to plot weekly water trap catches with maximum weekly temperatures.

2.4.1 SUCTION TRAPS

A 12-inch Johnson-Taylor suction trap was used on two separate occasions to determine flight take-off thresholds for *T. obscuratus*. A suction trap was placed in a sheltered position in the formal garden, Lincoln College (see Appendix 4) between 8 and 10 May 1985. Taped to the upper frame above the fan was a small vial (38 mm long x 15 mm dia.) containing about 2.5 mls of the thrips attractant, ethyl nicotinate (Penman *et al.* 1982), with a cotton-wool dental roll acting as a wick inside the vial. On the second occasion a suction trap was placed in a sheltered position beside a nectarine tree (var. unknown) situated on the Lincoln College campus (see Appendix 4) between 16 September and 8 October 1986. No attractant was attached.

Fan heights were 1.22 and 1.53 m above the ground respectively. Fan speed was set to normal and the catch-segregating discs were set to segregate hourly catches. Traps were serviced daily. All adult thrips were mounted and identified. The segregating discs and collecting cylinder were sprayed with a pyrethroid insecticide before being loaded into the suction trap.

Placed beside each suction trap at a height similar to that of the fan was a Stevenson screen containing a calibrated thermohygrograph for temperature recordings. Hourly catches of thrips in suction

traps were compared with maximum hourly temperatures to determine flight take-off thresholds (Lewis 1973).

2.4.2 WATER TRAPS

Thrips flights were sampled by water traps placed within and outside stonefruit blocks periodically from 1985 to 1987 (see Chapter VI for details). Thrips were removed from water traps about once a week and identified. Mean weekly catches of *T. obscuratus* were plotted against maximum weekly temperatures to determine flight take-off thresholds. Subsampled water trap catches were not included.

2.5 DIURNAL ACTIVITY.

Sampling to determine the diurnal activity of *T. obscuratus* was carried out on flowers of nectarine and cherry. For nectarine, flowers were sampled at approximately 80% full bloom from a single mature tree (var. unknown) situated on the Lincoln College campus (see Appendix 4). At each sample 50 flowers were picked from the tree below 2.5 m and 10 placed in each of 5 collecting cylinders (see Appendix 3).

For cherry, flowers were sampled at full bloom from five mature Yoshino cherry trees (*Prunus yedoensis* Matsum.) situated on the Lincoln College Campus (see Appendix 4). For each sample 20 flowers were picked from each tree below 2.0 m and placed in a collecting cylinder (see Appendix 3).

Samples were taken at 6 a.m., 9 a.m., 12 noon, 3 p.m., 6 p.m. and 9 p.m. on two consecutive days for nectarine (22 and 23 September 1986) and for cherry (1 and 2 October 1986).

Adult thrips were extracted from flowers with heat (see Appendix 3), mounted and identified.

Hourly temperature recordings for both nectarine and cherry were established from a calibrated thermohygrograph placed inside a Stevenson screen next to the nectarine tree.

For each day the mean number of thrips caught and temperature at each sample were plotted against time.

2.6 NATURAL ENEMIES

Parasitism by nematodes was not discovered until late in the course of this study. Unfortunately the preparation of thrips in alcohol and on slides was not suitable for the preservation of nematodes, so a measurement of percent parasitism could not be made nor could the nematodes be adequately identified.

To establish the identity of the nematodes, thrips were collected from peach fruit in March 1988 and killed in 4% formalin solution at 60°C (Wouts, W. pers. comm.). These specimens were then sent to Dr. Wim Wouts (Entomology Division, D.S.I.R., Auckland) to extract the nematodes for identification.

The seasonal occurrence of nematodes was established by examining monthly thrips samples (either alcohol or slide mounts) from August 1985 to July 1987. For each month samples were examined until the first nematode was observed or until all samples for that month had been examined. It was assumed that the presence of nematodes in thrips samples indicated parasitism of the thrips by the nematodes at that particular time.

3 RESULTS AND DISCUSSION

3.1 HOSTS

T. obscuratus was found and reported on at least 223 plant species from 177 genera and 77 families (Appendix 6). This list is much larger than the last established by Spiller and Wise (1982) and reinforces the common perception that *T. obscuratus* is a highly polyphagous insect (Mound and Walker 1982). There are probably still many more hosts. Adults were usually found in flowers (194 records) but were also common on leaves (38) and fruit (32) from most areas in New Zealand as defined by Crosby *et al.* (1976), except WA (Wairarapa) and NC (North Canterbury).

The presence of adults alone on a plant does not necessarily indicate a feeding or breeding host, and therefore most of the following discussion concerns breeding hosts as indicated by the presence of larvae (Table 4.1). Plant samples were not taken randomly, so there is a possible bias in the host species lists.

Forty-nine breeding hosts were established for *T. obscuratus* from 43 genera and 22 families in Canterbury (Table 4.1). All larvae were found in flowers apart from two records from the fruit of stonefruit. Larvae were found in hosts throughout the year with only two months, September and June, not represented. Most hosts were found from October through to January. Adults were collected from all months of the year (Appendix 6). The seasonal abundance of *T. obscuratus* is examined in more detail in Chapter VI.

Flowers are inhabited by a number of thrips species, including other members of the Thripini (Mound *et al.* 1980). The flower provides an ideal environment for thrips development with provision of oviposition sites, adult and larval feeding sites and nutrient sources to promote oviposition and larval development. Insects that exploit the energy rich tissues of flowers and developing fruit will have an evolutionary edge over their congeners (Pellmyr and Thien 1986). Larvae of other thrips species on the fruit of stonefruit are uncommon, but *T. obscuratus* has been associated with ripe stonefruit for some time (Spiller 1951, Penman *et al.* 1982). This will be examined in detail in Chapter V.

Plant families well represented among the host species included the Asteraceae (3 breeding, 16 adult), the Fabaceae (11, 21) and the Rosaceae (9, 20), but otherwise hosts were widely spread through other plant families. The wide range of hosts makes generalisations about specific host requirements difficult. Floral colour was predominantly white or yellow (Table 4.1). The relative attractiveness of fruit and flowers in terms of odour and colour will be examined in Chapter VII.

The list contains more hosts plants of introduced origin (35 breeding, >140 adult) than endemic hosts (14, 67), but this probably reflected the sampling procedure. It is obvious that *T. obscuratus* has colonised many introduced plants, and the belief of Mound (1978) that it has become increasingly common since the introduction of exotic plants is reinforced. The polyphagous behaviour of *T. obscuratus* is still evident among the endemic species, with larvae collected from 14 (adult 67) species, 12 (45) genera and 9 (34) families.

TABLE 4.1: LARVAL HOST PLANTS OF THE NEW ZEALAND FLOWER THRIPS IN CANTERBURY.

KEY
MONTH (SAMPLE DATE): i = JANUARY ii = FEBRUARY etc.
STAGES: F=FEMALE (>1) f=FEMALE (at least 1)
M=MALE (>1) m=MALE (at least 1)
* ENDEMIC TO NEW ZEALAND
^{t} HEAVILY INFESTED WITH LARVAE
$^{\#}$ LARVAE COLLECTED FROM FRUIT

HOST FAMILY AND SPECIES	COMMON NAME	MONTH	STAGE	FLOWER COLOUR
ANGIOSPERMAE-MONOCOTYLEDONS				
AGAVACEAE				
*Cordyline australis	ti kauka/cabbage tree	xi	F m^{t}	white
*Phormium tenax	harakeke/N.Z. flax	xi	F M^{t}	dull red
ANGIOSPERMAE-DICOTYLEDONS				
APIACEAE				
*Anisotome aromatica		xii	F M^{t}	white
ASTERACEAE				
Achillea millefolium	yarrow	v	F	yellow
*Celmisia spectabilis	cotton plant	ii	f	white/yellow
Dahlia sp.	dahlia	iv	F M^{t}	pink
BIGNONIACEAE				
Catalpa bignonioides	Indian bean tree	i	F m^{t}	white/yellow/brown
BRASSICACEAE				
Brassica hirta	mustard	viii	F	yellow
Brassica oleracea	brussels sprout	x	f	yellow
BUDDLEJACEAE				
Buddleia davidii		i	F m	
CAPRIFOLIACEAE				
Sambucus nigra	elder	xii	f m^{t}	white
Viburnum tinus	laurustinus	v,vii	F M^{t}	white
CORNACEAE				
*Corokia x virigata		xi	f	orange/yellow
ERICACEAE				
*Gaultheria rupestris		xii	F M^{t}	white
FABACEAE				
*Carmichaelia odorata		i	F m	white/purple
Cytisus scoparius	Scotch broom	i	f	yellow
Chamaecytisus palmensis	tree lucerne	x	F M^{t}	white
Lupinus polyphyllus	Russell lupin	i	F m	
Medicago sativa	lucerne	i	f	purple
Robinia pseudoacacia	black locust	xi	F	white
*Sophora tetraptera	kowhai	xi	f M	golden yellow
Trifolium pratense	red clover	i	F m	purple
Trifolium repens	white clover	i	F M	white
Ulex europaeus	gorse	iv,v,vii	F m^{t}	yellow
Vicia faba	broad bean	x	f m	white/purple
HIPPOCASTANACEAE				
Aesculus indica	Indian horse-chesnut	xii	f m	white
LAMIACEAE				
Rosmarinus officinalis	rosemary	x	f	
MALVACEAE				
Althaea officinalis	marsh mallow	i,ii	f	blue
*Hoheria angustifolia		i	F	white
*Hoheria sexstylosa	ribbonwood	iii	F M^{t}	white
MYRTACEAE				
*Kunzea ericoides	kanuka/tea-tree	i	F m^{t}	white
*Leptospermum scoparium	manuka/tea-tree	i	F ^{t}	white
ONAGRACEAE				
Fuchsia x hybrida	fuchsia	i	m	red

TABLE 4.1 : continued

OLEACEAE				
Ligustrum sp.	privet	i	F[t]	white
PHILADELPHACEAE				
Deutzia sp.	deutzia	xii	f m	
ROSACEAE				
Crataegus x lavallei		xi	f	white
Cydonia oblonga	quince	x	F m	white
Malus sylvestris	apple	x	f m	white
Prunus armeniaca	apricot	i	F m[#]	
Prunus persica	peach	x	F M	pink
		i,iv	F M[#]	
Prunus persica	nectarine	x	F M	pink
Prunus yedoensis	Yoshino cherry	x	F	pink
Pyrus communis	pear	x	M	white
Rosa sp.	rose	iii,iv	F M	white
Rubus fruticosus	blackberry	i	F	white
RUTACEAE				
Choisya ternata	Mexican orange	xi	F m	white
SAXIFRAGACEAE				
Astilbe x arendsii		xii	F	white
SCROPHULARIACEAE				
*Hebe speciosa		i	F M	reddish magenta
*Hebe vernicosa		xii	F M	white
STYRACACEAE				
Pterostyrax hispidus		xii	F m	white

Breeding hosts included vegetables (e.g., *Brassica* sp., *Vicia* sp.), garden flowers (e.g., *Dahlia* sp., *Rosa* sp.), herbs (e.g., *Rosmarinus* sp.), ornamental trees and shrubs (e.g., *Viburnum* sp., *Hoheria* spp., *Ligustrum* sp., *Hebe* spp.), fruit trees (e.g., *Malus* sp., *Prunus* spp., *Pyrus* sp.), pasture plants (e.g., *Trifolium* spp., *Medicago* sp.), and weeds (*Achillea* sp., *Cytisus* sp., *Lupinus* sp., *Ulex* sp., *Rubus* sp.).

The total removal of the host plants of *T. obscuratus* in the vicinity of stonefruit orchards is impractical. However, in early spring few plants are flowering, so that thrips breeding sites are minimal. The few breeding hosts that do flower at this time, such as gorse and *Viburnum*, supply breeding and feeding sites for thrips which can then invade the orchard. Removal of these plants near the orchard or treatment with insecticides should reduce the thrips population entering the orchard in spring. Unsprayed stonefruit trees should be treated in a similar fashion. Due to the number of host plants flowering at fruit harvest, host plant removal at this time is not feasible.

The removal or cultivation of ground cover before stonefruit flowering has reduced russet in nectarines both overseas (Bailey 1938, La Rue *et al.* 1972) and in New Zealand (Anon. 1979). The presence of thrips breeding and feeding hosts such as dandelion, in the ground cover at this time supplies an immediate source of thrips to infest stonefruit flowers. Removal of these plants forces the adults to find hosts elsewhere, kills the larvae and causes emigration of the pupae that reach eclosion. Removal of these hosts during flowering encourages thrips to move into the stonefruit flowers and fruit damage is increased (La Rue *et al.* 1972, Anon. 1979). Good management would ensure the removal of these hosts before and not during stonefruit flowering.

Adult *T. obscuratus* were found on the catkins of willows and appeared to be feeding on the pollen. The willows were planted as a shelter for stonefruit and both willow and stonefruit were flowering

simultaneously. This alternative feeding site for thrips close to the flowering stonefruit trees may encourage the presence of thrips within the orchard. Other shelter species such as poplars may prove more suitable for reducing thrips infestation within the stonefruit orchard.

3.2 PHENOLOGY ON STONEFRUIT FLOWERS

The mean number of adult and larval thrips extracted during nectarine and peach flower development are shown in Figures 4.1 and 4.2 for 1986 and 1987 respectively along with maximum and minimum daily temperatures. Standard deviations for thrips numbers were large, sometimes twice that of the mean. Some of this error was possibly due to small sample sizes, but the raw data was inherently variable with many zero counts. Nevertheless the mean values show the broad pattern of thrips infestation in these flowers.

Flowers were infested with thrips adults at 90% pink and adults were found in similar numbers throughout flower development. On nectarine in 1986 adults were never found in numbers of more than 0.6 per 10 flowers. Up to 3 adults per 10 flowers were found on peach and nectarine in 1987. The most common thrips sampled were *T. obscuratus* females. Males were present only after petal fall in 1987. A small number of other thrips species was present (Table 4.2).

Larvae were almost entirely absent at pink; numbers were low at full bloom and peaked at or just after petal fall. Peak numbers were 7.5 larvae per 10 flowers in 1986 and 12 and 15.5 larvae per 10 flowers on peach and nectarine respectively in 1987. Larval numbers declined steadily after petal fall and there were few present at shuck fall. Large larvae which were probably second instars were found in the samples from petal fall onwards. Smaller larvae, probably first instars, were present throughout flower development. Larvae collected from flowers at petal fall in 1987 and reared to adults for identification were all *T. obscuratus*. On peach there were 10 females and 12 males and on nectarine 16 females and 7 males. Adult and larval infestation of flowers was higher in 1987 than in 1986. This may have been due to the large variety of flowering plant species which supported thrips populations in the vicinity of the trees in 1987. The immediate environment of the nectarine tree in 1986 was more homogeneous with fewer sources of thrips infestation.

Several species of thrips were caught in the water traps throughout the sampling period (Figure 4.3). *T. obscuratus* was the most abundant species. Females were more common until 8 October, after which time males and females were caught in similar numbers. Other species trapped included *Thrips tabaci, Limothrips cerealium* and *Chirothrips manicatus* (see Appendix 7). Even though other thrips species were flying in the orchard throughout flowering, *T. obscuratus* was the predominant species infesting the flowers.

The levels of adult infestation during flowering were comparable with those found by Cravedi *et al.* (1983) and Cravedi and Molinari (1984) on untreated nectarine trees. They found a maximum of 50 adult thrips per 100 flowers, but usually there were fewer than 20 adults per 100 flowers. Allman (1948b) also stated that levels of fewer than one thrips per flower were found at full bloom and at petal fall.

FIGURE 4.1: THRIPS INFESTATION OF NECTARINE FLOWERS IN RELATION TO FLOWER PHENOLOGY AND TEMPERATURE IN 1986.

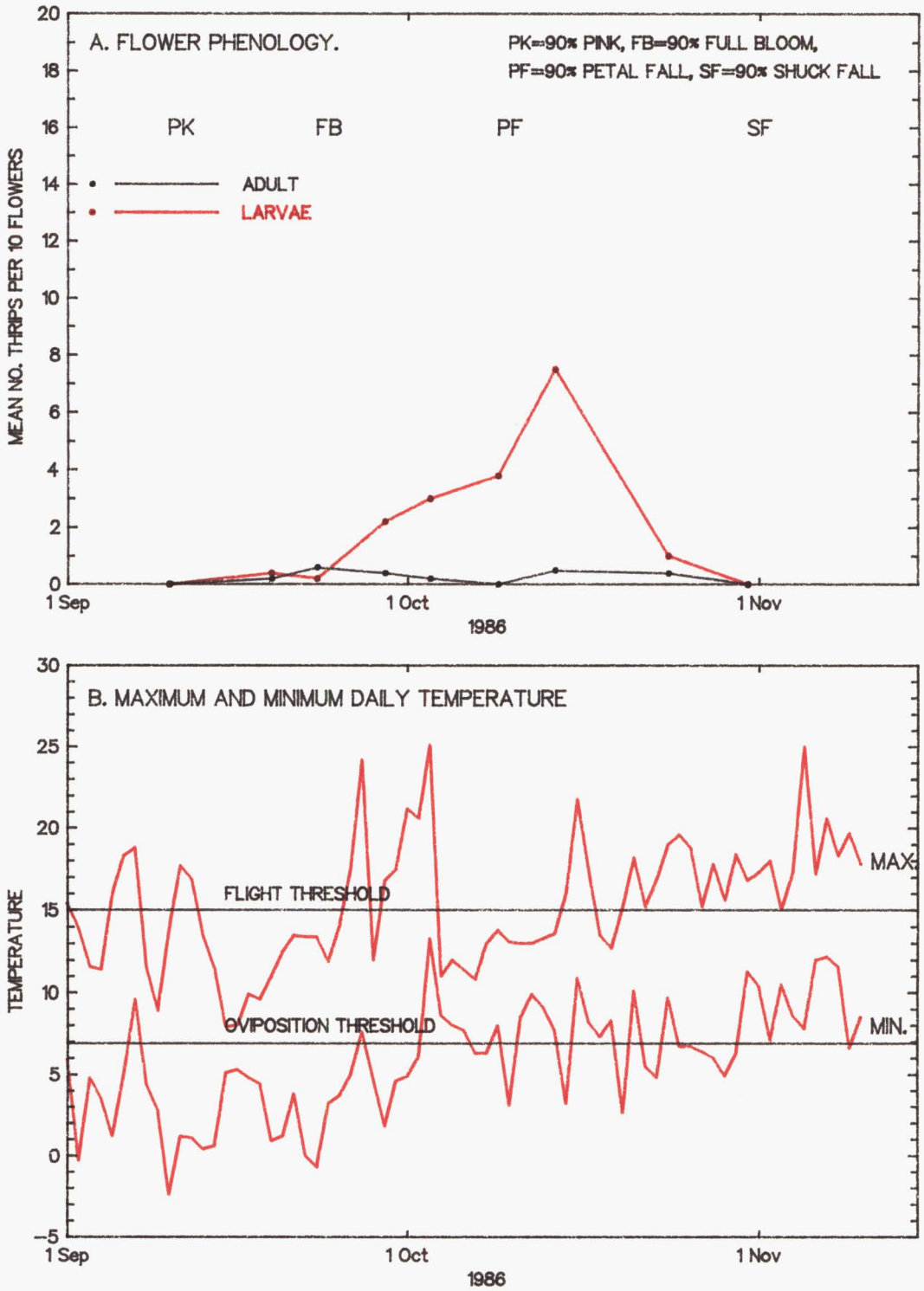


FIGURE 4.2: THRIPS INFESTATION OF NECTARINE AND PEACH FLOWERS IN RELATION TO FLOWER PHENOLOGY AND TEMPERATURE IN 1987.

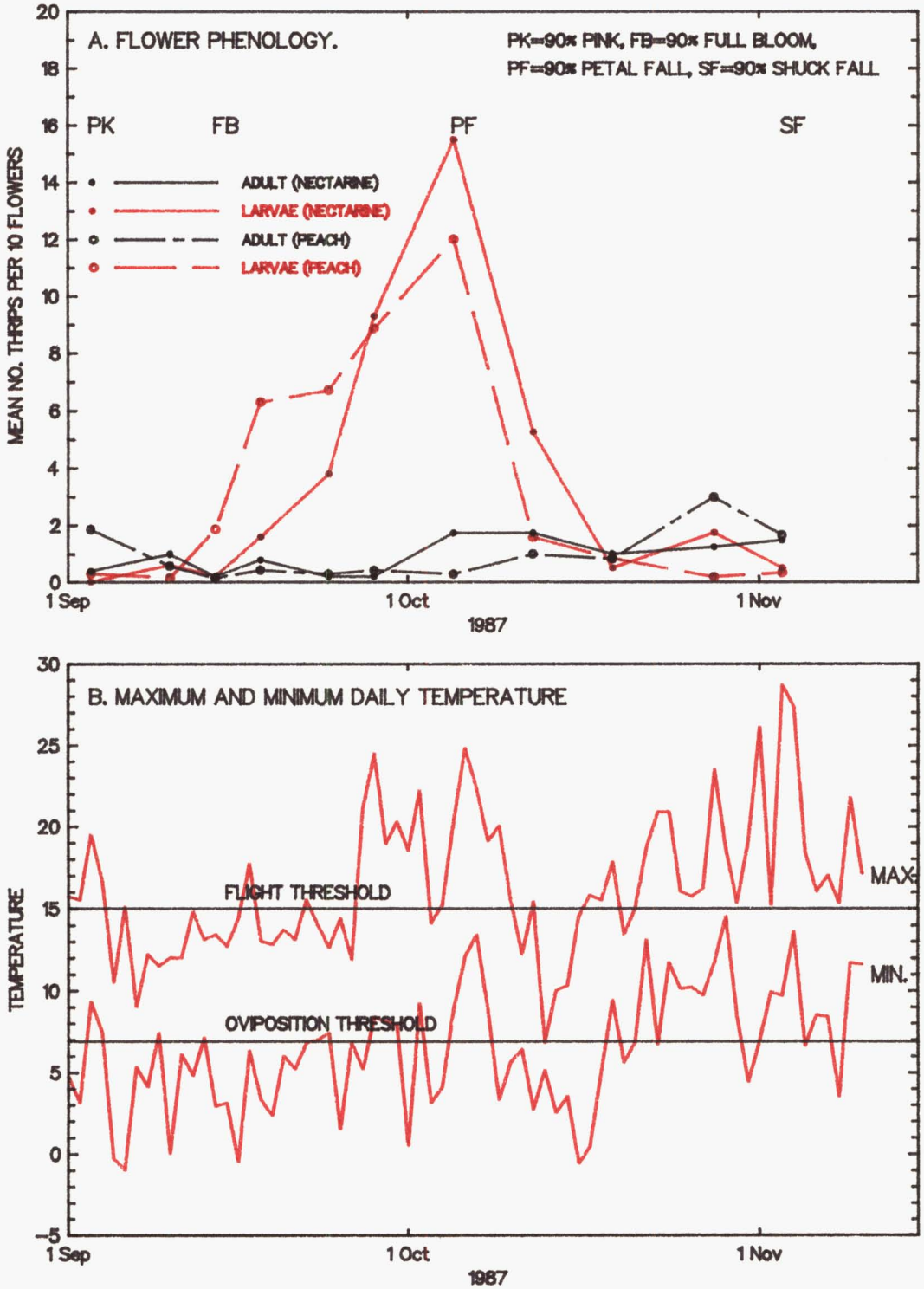
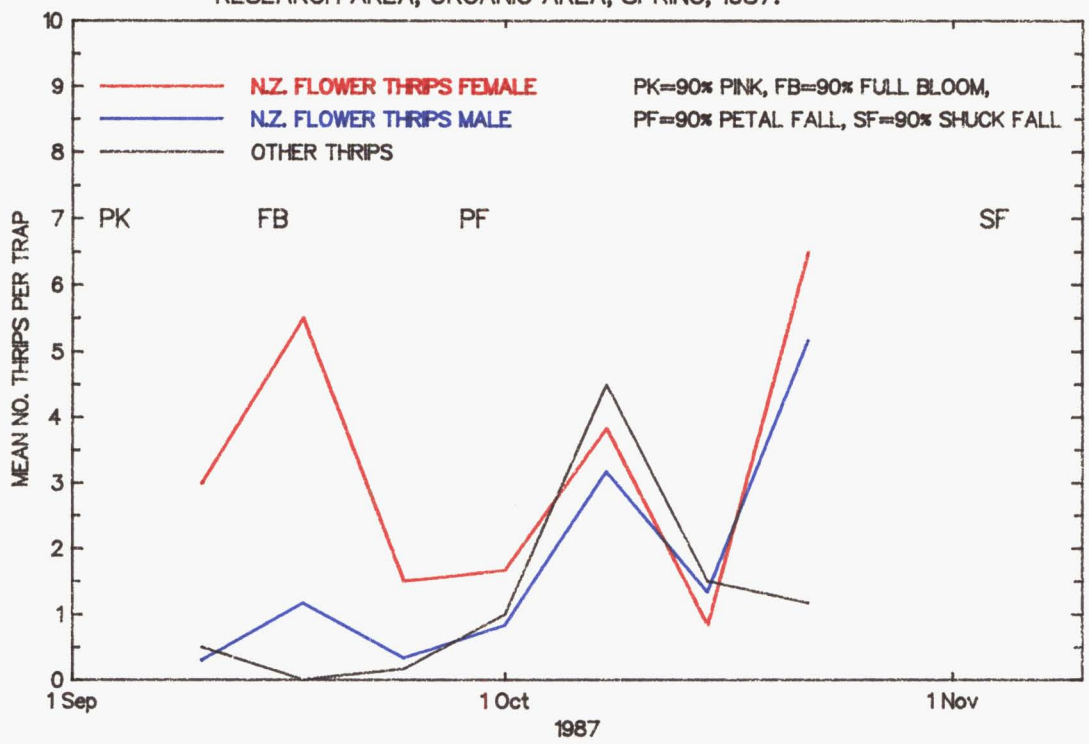


TABLE 4.2: IDENTITY AND NUMBER OF ADULT THRIPS EXTRACTED FROM NECTARINE AND PEACH FLOWERS.

	Thrips obscuratus		Other species
	Females	Males	(All females)
Nectarine 1986	10	0	1 *Limothrips cerealium* 1 unidentified
Nectarine 1987	33	9	1 *Thrips australis*
Peach 1987	52	15	1 *Thrips tabaci* 1 *Chirothrips manicatus* 2 Tubilifera

FIGURE 4.3: THRIPS CAUGHT IN WATER TRAPS, LINCOLN COLLEGE HORTICULTURAL RESEARCH AREA, ORGANIC AREA, SPRING, 1987.



Quantitative estimates of larval infestation throughout flowering have not been reported, even though larval feeding is considered to be the prime cause of fruit damage (Allman 1948b, La Rue *et al.* 1972, Bournier 1970, Cravedi and Molinari 1984). About two larvae per flower were found in nectarine blossoms at petal fall by Allman (1948b). Bailey (1938) stated that larvae were most common after full bloom, and they have been observed until shuck fall (Black *et al.* 1963, La Rue *et al.* 1972). These data are therefore the first to show the levels of larval infestation throughout flowering.

Maximum daily temperatures exceeded the flight take-off threshold of 15°C for *T. obscuratus* (see below) early in flower development in both seasons (Fig. 4.1b, 4.2b).

Therefore females thrips were probably laying eggs from pink onwards in the tender floral tissues where thrips eggs are found (McLaren 1983b, 1986). Throughout flower development during both seasons, maximum daily temperatures (Figures 4.1b and 4.2b) often exceeded the oviposition threshold of *T. obscuratus* of 6.9°C established in Chapter III. Oviposition was likely to have continued to at least petal fall. Allman (1948b) observed the eggs of *Thrips imaginis* on nectarine sepals at this stage. The general disintegration of the flower after this time may make conditions unsuitable for oviposition.

Mean daily temperatures were about 10°C throughout the early flowering period in both seasons. At 10°C in the laboratory egg development took 12 (female) and 13 (male) days (Table 3.4). Assuming initial oviposition at 90% pink, egg hatch would be expected to begin about 12 days after pink or close to full bloom. At this time larval numbers were increasing steadily in the field samples. At 10°C in the laboratory larval development took 22.3 (female) and 16.9 (male) days (Table 3.4). This period of larval development after full bloom coincided with maximum larval numbers in the field data between full bloom and petal fall. The presence of some larvae in flowers in the field samples before full bloom was probably due to eggs laid in flowers before 90% pink. The presence of larvae, some of which were small and almost certainly first instar, late in the field samples is explained by oviposition after pink.

Larval numbers declined sharply after petal fall. This may have been due to high egg mortality at petal fall and/or high larval mortality after petal fall. Egg mortality may have been the result of reduced humidity or mechanical injury, as the hypanthium and other floral tissues distorted and dried out with floral disintegration. Humidity was important to egg development in the laboratory studies (see Chapter III) and Rivnay (1935) found thrips eggs to be injured when host leaves were distorted through excessive evaporation. Alternatively, the reduction in larval feeding sites in the flower after petal fall due to the abscission of many floral tissues may promote larval mortality. In either case, if larval development were completed by petal fall thrips mortality would be lower.

These samples did not determine if larval development was completed before petal fall after which time larval survival is unlikely. The time of egg to completion of larval development at 10°C in the laboratory was about 34 (female) and 30 (male) days (Table 3.4). Thirty days after pink was close to petal fall in both seasons. Assuming that some of the female colonists were virgins, their offspring would be only males (see Chapter III). In 1987 the sudden increase in males in water traps on 8 October and the presence of males in flower samples from 5 October onwards suggests that these males were offspring of the initial colonists laying eggs at pink. Males were not, however, found in any flower samples in 1986. In this season male and female offspring of colonial females may be absent because there was insufficient time to complete larval development before petal fall. Thus the appearance of males after petal fall and thrips mortality in stonefruit flowers appears to be directly related to the speed of development of thrips in relation to flower phenology between pink and petal fall.

These circumstances may help explain the occurrence of male thrips on nectarine trees in Central Otago. In some seasons males appear in early October (McLaren 1986), but in others they are absent till late October (McLaren 1985).

In Central Otago on sour cherries, 25 days elapsed between oviposition at full bloom and adult emergence (McLaren 1983, 1984). The first appearance of males in flower samples in 1987 probably coincided with the maturity of eggs laid at pink. From 90% pink to the appearance of adult males 33 days elapsed. Cherries tend to bloom slightly later than nectarines, so conditions may have been warmer and hastened development times in Central Otago. Nevertheless McLaren's development times appear to be an underestimate. Perhaps, as in the case of other flowers, oviposition within cherry flowers took place earlier at pink.

On the single nectarine tree sampled in 1986, 3,535 flowers were counted at 80% full bloom (23/9). Flower numbers appeared to remain static until after petal fall (14/10), when it was noticed that many flowers had died as a result of twig dieback due to brown rot (*Monilinia fructicola*). Throughout the sampling period adult thrips were commonly found at about 0.4 thrips per 10 flowers (Figure 4.1). This would indicate that the whole tree was infested with about 140 adult thrips throughout flower development. Larval numbers per flower peaked at 7.5 per 10 flowers after petal fall (14/10) (Figure 4.1). However, the number of flowers on the tree had declined at this time. Therefore the larval numbers at petal fall (9/10) may give a better estimate of the total number of larvae per tree. At petal fall 3.8 larvae per 10 flowers were found or about 1340 thrips per tree.

Although fruit were not assessed for damage it was observed that virtually all nectarines on the sample trees exhibited typical symptoms of thrips feeding such as irregularly-shaped blocks of russet and scar lines over the fruit (see Plate 2). Peach fruit damage on the sample trees was limited. It is generally considered that nectarines are more susceptible to thrips damage at flowering than peaches (Bailey 1938, Kemp 1959).

The presence of larvae feeding at petal fall is considered to be the main source of damage to young nectarine fruit overseas (Allman 1948b, Black *et al.* 1963, Bournier 1970, La Rue *et al.* 1972, Cravedi and Molinari 1984). In New Zealand, McLaren (1986) established that the critical period was slightly earlier as a result of bagging experiments with adult thrips. Although she had reported the presence of thrips larvae in nectarine flowers and on fruitlets throughout October and November (McLaren 1981, 1983b) she did not associate them with fruit damage. Possibly her sampling method was inefficient at establishing the level of larval infestation. On unsprayed stonefruit trees in Canterbury, larval numbers at petal fall were about 10x those of adults at any time during flowering. Larval feeding does not differ significantly from that of adults, so the large larval population at petal fall when the ovary remains the most succulent floral tissue must be a significant factor in the amount of damage suffered by nectarine fruitlets. This should be considered in the development of control programmes.

3.3 PUPATION

From the initial sample of litter beneath the cabbage tree two larvae, one prepupa and eight pupae were collected. Of these, six individuals developed to adults. Three male and three female *T. obscuratus* were identified. These results are the first records of pupation sites for *T. obscuratus* in natural conditions.

Although Berlese-Tullgren funnels are often used for extraction of thrips from soil, they are considered to be useless for pupae (Lewis 1973). In these samples only one pupa was extracted from 0.471

square metres of litter and 0.188 cubic metres of soil. Considering the ease of finding larvae by hand searching in the initial sample, the efficiency of pupal extraction by funnels was very low. A number of adults were extracted by the funnels. Presumably these were newly emerged adults or pupae that were close to eclosion on the sample date and developed to adults in the warmth of the extraction funnels. Adults were extracted from all substrate levels and were mostly *T. obscuratus* females and males (Table 4.3).

TABLE 4.3: THRIPS ADULTS EXTRACTED FROM LEAF LITTER AND SOIL BENEATH A CABBAGE TREE AT LINCOLN COLLEGE.

	Thrips obscuratus		Others species
	Females	Males	(All females)
Leaf litter	10	8	1 Tubilifera
Soil 0-20 mm	8	3	1 Tubilifera
Soil 40-60 mm	3	0	1 *Limothrips cerealium*

These results show that pupation in *T. obscuratus* takes place in leaf litter and soil beneath cabbage trees. Previously pupae have only been recorded from caged flowers (Mound and Walker 1982, McLaren 1985). It is probable that the soil is a common pupation site with other host plants. Both Mound and Walker (1982) and McLaren (1985) thought that *T. obscuratus* pupated in the ground as is the case with other terebrantians (Mound and Walker 1982).

Directing control measures against the soil-inhabiting stages of polyphagous, polyvoltine thrips species is difficult, as pupation occurs throughout the year and sites may be widespread.

3.4 FLIGHT TAKE-OFF THRESHOLDS

3.4.1 SUCTION TRAPS

Hourly catches of thrips for 1985 and 1986 were combined and plotted against maximum hourly temperatures. Generally numbers trapped were low, but the Johnston-Taylor suction trap probably did not sample thrips flight accurately. Some individuals were trapped at night at very low temperatures (e.g., 8 p.m. -5^{o}C, 9 p.m. -10^{o}C, 1 a.m. -10^{o}C). These are well outside flight take-off thresholds established for other temperate thrips species (Lewis 1973). These results may be explained by thrips slipping or crawling between the collecting discs of the Johnstone-Taylor trap. Gassen,D. (pers. comm.) encountered similar

problems using a Johnstone-Taylor suction trap to sample *Listronotus bonariesis* (Kuschel). He resorted to placing the collection cylinder in alcohol to stop movement of insects between discs after capture. These results are therefore not considered representative of thrips flight.

3.4.2 WATER TRAPS

Mean weekly water trap catches of *T. obscuratus* females and males for 1985 to 1987, excluding weeks that were subsampled, are plotted against maximum weekly temperature in Figure 4.4. These data clearly indicate that flying thrips were caught mostly when the temperature was 15°C or above. The small number of females caught below 15°C may reflect climatic differences between the meteorological station and the orchard. The flight take-off threshold of 15°C is the same as that established by McLaren (1981) using a suction trap in Central Otago, although it is slightly lower than thresholds of 17-20°C common for temperate thrips species (Lewis 1973). Daily flight trap data from sticky board samples indicated that most thrips were caught when maximum temperatures exceeded 19°C (McLaren 1985). The fact that many thrips were commonly trapped at weekly maximum temperatures below 19°C in these data indicates that 19°C is not the flight take-off threshold.

3.5 DIURNAL ACTIVITY

The mean number of adult thrips sampled from 6 a.m. to 9 p.m. from nectarine and cherry flowers were plotted against time and temperature (Figure 4.5). On nectarine all thrips were *T. obscuratus* females. Sixteen out of the total of 25 thrips on cherry were *T. obscuratus* females. Although numbers sampled were low, there was no correlation between thrips numbers and time of day or temperature. Thrips were usually present in flowers from 6 a.m. to 9 p.m., irrespective of temperature. Weather was fine and clear for 22 and 23 September and 1 October but overcast on 2 October.

These results indicate that there is no restriction on the period of sampling for thrips on stonefruit in Canterbury as was found in Central Otago (McLaren unpubl.). It is difficult to reconcile these contrasting observations. Trees in Central Otago may have received insecticide applications, which may have influenced thrips behaviour. Different local conditions or sampling methods may also have been important.

3.6 NATURAL ENEMIES

Spilomena sp. (Hymenoptera : Sphecidae : Pemphredoninae) are known predators of *T. obscuratus* in New Zealand (Mound and Walker 1982, Vardy 1987). Early, J. (pers. comm.) observed *Spilomena nozela* Vardy capturing *T. obscuratus* adults from *Astilbe* flowers on the Lincoln College campus. However, no specimens of any *Spilomena* sp. were extracted from stonefruit flower samples on either sprayed or unpsrayed trees and no *Spilomena* sp. were observed preying on thrips on ripe stonefruit.

There was little evidence of other predators regulating thrips populations in stonefruit orchards for the duration of this project.

FIGURE 4.4: APPARENT FLIGHT TAKE-OFF THRESHOLD TEMPERATURES FOR THE N.Z. FLOWER THRIPS BASED ON WEEKLY WATER TRAP CATCHES AND MAXIMUM WEEKLY TEMPERATURES.

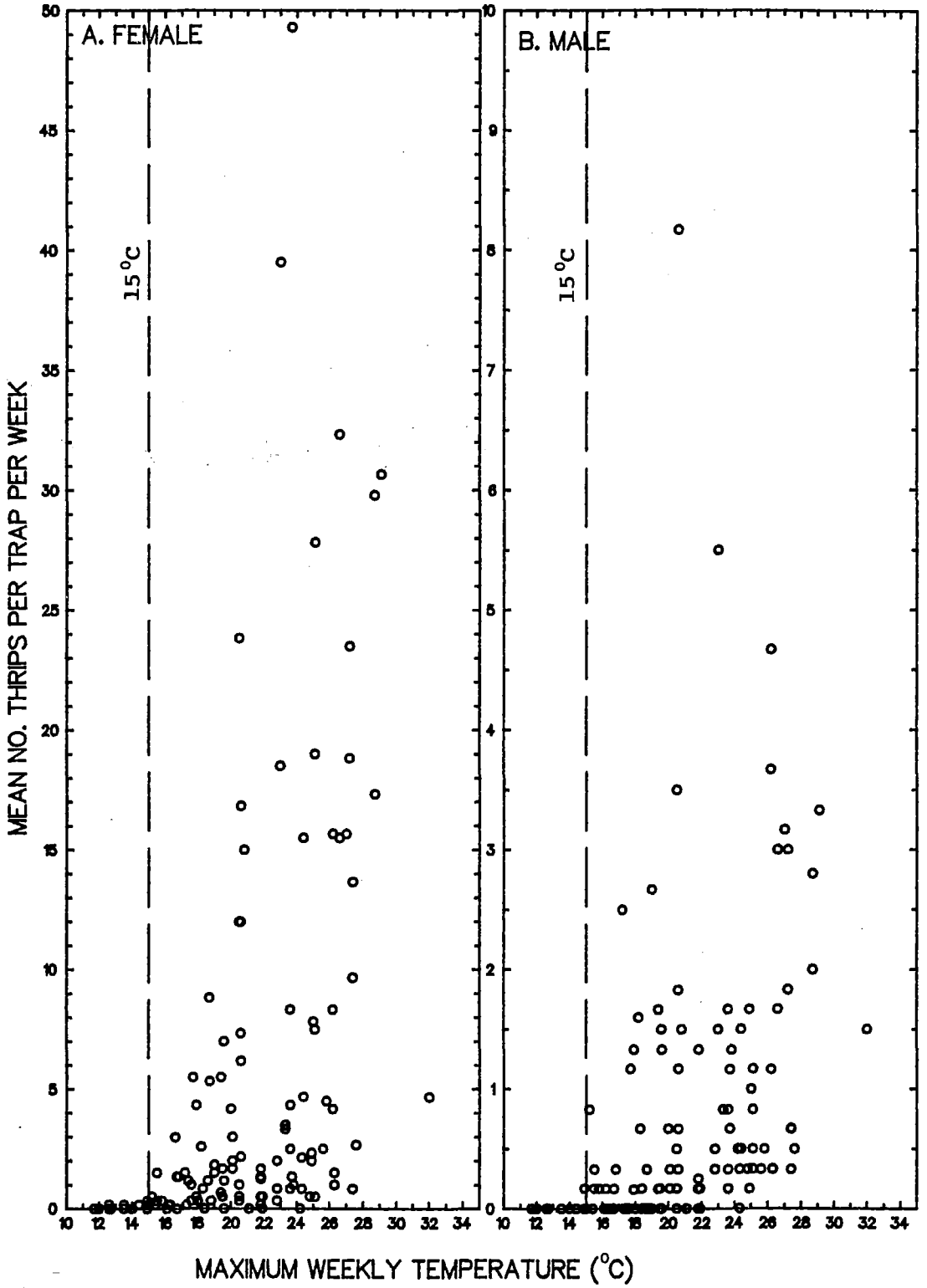
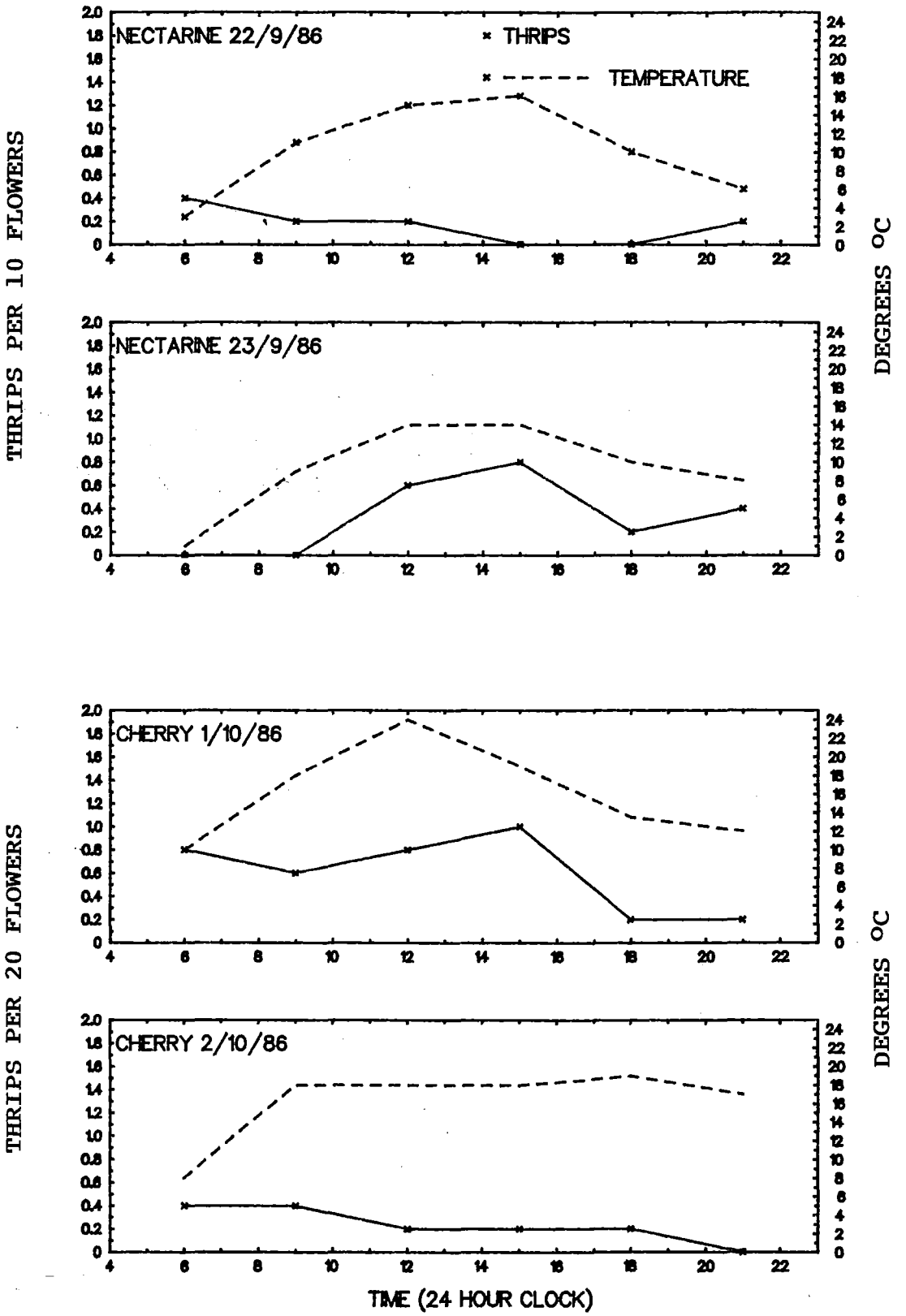


FIGURE 4.5: THRIPS INFESTING STONEFRUIT FLOWERS AT FULL BLOOM IN RELATION TO TIME OF DAY AND TEMPERATURE.



The nematodes found in thrips sampled from peaches in March 1988 have been preliminary identified as *Howardula aptini* (Sharga) belonging to the family Sphaerularidae (Wouts, W. pers. comm.). The nematodes were larvae, and for conclusive identification the female is needed (Wouts, W. pers. comm.). *Howardula aptini* is the only nematode listed in association with thrips by Poinar (1975). The symptoms exhibited by parasitised thrips during this study, such as sterilisation by numerous larval nematodes in the thrips abdomen (see Plate 5), are similar to observations of *Howardula aptini* reported in the literature. Therefore it seems probable that this nematode is *Howardula aptini*. Wouts, W. (pers. comm.) found that about 5% of the thrips supplied to him were infected with nematodes.

In alcohol and slide samples of thrips taken between August 1985 and June 1987, nematodes were found in all months except for August 1985 and July, August and September 1986. The absence of nematodes in these months may be a reflection of the limited number of samples. Other thrips infected with *Howardula aptini* have been found at all times of the year (Lewis 1973).

The significance of nematodes in thrips population regulation and for biological control is questionable. Parasitism rates by *Howardula aptini* in other thrips were as high as 60 to 70 percent (Sharga 1932, Nickle and Wood 1964, Reddy *et al.* 1982), but because of the short generation time and high fecundity of *T. obscuratus* (see Chapter III) parasitism may not affect the overall population size.

Nickle and Wood (1964) thought that introduction of the nematode into unparasitised populations was feasible, as did Reddy *et al.* (1982) who also stated the nematode could be used for biological control of thrips.

Future work in this area should clearly identify the nematode species, investigate the effect of the nematodes on thrips reproduction, determine levels of parasitism throughout the season, and assess the importance of parasitism in relation to thrips population numbers. Only then could an objective decision be made about its application for biological control.

4 SUMMARY

The New Zealand flower thrips was found to inhabit a large number of endemic and introduced plants. Thrips were collected and reported on at least 223 separate species from 176 genera and 77 families. Adults were usually found on flowers but were also common on leaves and fruit. *T. obscuratus* adults were collected from all parts of New Zealand. Larvae were taken from 49 species from 43 genera and 22 families from plants around Canterbury. All larvae were on flowers except for two records from the fruit of stonefruit. Both adults and larval hosts were found throughout the year but were most common in early summer.

Removal of early flowering hosts in the vicinity of stonefruit orchards before flowering may prove advantageous for reduction of thrips populations on stonefruit flowers. At other times of the year the large number of hosts precludes this.

Adult and larval thrips infesting flowers of unsprayed stonefruit trees were almost all *T. obscuratus*, and adults were mostly female. Adult males caught late in flower development were probably from eggs laid at pink.

Adults and larvae of thrips were found in flowers of unsprayed nectarine and peach trees from pink to shuck fall. Adults were found in similar numbers throughout flower development, seldom reaching more than 2 thrips per 10 flowers. Larvae were almost entirely absent at pink; numbers were small at full bloom and peaked at or just after petal fall. Peak larval numbers were between 7-15 thrips per 10 flowers. The decline in larval numbers coincided with the disintegration of the flower after petal fall.

It was estimated that up to 140 adults and 1340 larvae infested flowers of a single unsprayed nectarine tree at petal fall. Larval feeding was considered to be a significant factor in damage to young nectarine fruit.

Pupation sites for *T. obscuratus* were established as including the soil and litter beneath a flowering cabbage tree (*Cordyline australis*). Apart from caged flowers, these are the first records of pupation sites for *T. obscuratus*.

Flight take-off thresholds of 15^{o}C were established from weekly water trap samples for both adult male and female *T. obscuratus*.

Female *T. obscuratus* were parasitised by a nematode thought to be *Howardula aptini*.

CHAPTER V

THRIPS ON RIPE STONEFRUIT

1 INTRODUCTION

Adult thrips, particularly the New Zealand flower thrips (*Thrips obscuratus*), infest ripe stonefruit including peaches, nectarines and apricots (Spiller 1951, McLaren 1982, Penman *et al.* 1982, Tomkins 1985). They lay eggs within the skin, from which the larvae hatch (McLaren 1986, Chapter IV). Thrips infestation of stonefruit is important in New Zealand, as many export markets place severe restrictions on pest damage and infestation of food products. There are few reports of thrips exhibiting similar behaviour overseas (e.g., La Rue *et al.* 1972, Pollini and Giunchi 1979).

Thrips research on ripe stonefruit in New Zealand was initially centered on preharvest insecticide applications and general ecology of thrips (McLaren 1982-87). Recently postharvest disinfestation has also become a prominent area of research (McLaren and Dale 1987). There has been little work in New Zealand to determine the extent of thrips infestation on fruit, the composition of the thrips species and seasonal and varietal influences. This knowledge is also lacking for thrips infesting ripe stonefruit overseas, and is essential for informed decision making in pest management..

The aim of the work described in this chapter was to examine thrips infestation on ripe stonefruit. The numbers and species of thrips on fruit at different maturities and on different varieties throughout the season were determined.

2 MATERIALS AND METHODS

Peach, nectarine and apricot fruit were sampled for thrips adults, eggs and larvae from a stonefruit variety block (Block 1) in the Lincoln College Horticultural Research Area (Appendix 5). Samples were taken over three seasons and included several peach and nectarine varieties. Leaf clusters in the vicinity of fruit were sampled for thrips on one occasion. Table 5.1 lists the type and variety of stonefruit, number of sample trees and sample and harvest dates. Where possible, fruit were sampled to cover the three-week period of development before fruit maturity (local market). Pesticide applications during the sampling period are detailed in Appendix 5. Few pesticides were applied at the time of fruit maturity, so that every sample was taken at least 12 days after the previous insecticide application.

On each sample date for each variety, fruit reflecting the average ripeness of the sample tree (or trees) were picked below 2 m. Fruit were sealed individually in plastic bags immediately after picking and placed in a refrigerator (4^{o}C) in the laboratory until they could be examined for thrips. Leaf clusters were

TABLE 5.1: SAMPLE AND HARVEST DATE FOR STONEFRUIT, LINCOLN COLLEGE HORTICULTURAL RESEARCH AREA, BLOCK 1.

Variety#	No. trees	Sample No.* 1	2	3	4	5
1984-85						
Golden Queen P	4	4/3/85	12/3/85	18/3/85		
1985-86						
Red April P	2	11/12/85	17/12/85			
Springcrest P	2	11/12/85	17/12/85	26/12/85	3/1/86	
Redhaven P	2	26/12/85	3/1/86	9/1/86	16/1/86	21/1/86
Fayette P	1	4/2/86	12/2/86	19/2/86		
Fairtime P	2	10/3/86	17/3/86			
Flavourtop N	2	4/2/86	12/2/86	19/2/86	24/2/86	
Autumn Grand N	2	28/2/86	7/3/86	14/3/86		
Roxburgh Red A	1	20/1/86				
1986-87						
Redhaven P	1	14/1/87	20/1/87	26/1/87		

* the final sample date for each variety was the harvest date

\# P = peach, N = nectarine, A = apricot

treated as a single unit and bagged in a similar fashion. In the laboratory, fruit and leaf clusters were examined for adults with the naked eye and for larvae under a binocular microscope (x 10). For 'Fayette' and 'Fairtime' peaches, 'Flavourtop' nectarines and 'Redhaven' peaches (only 1986-87), larvae were examined to determine if they were alive. All adults and larvae were placed in A.G.A. solution (60% ethanol, glycerine, acetic acid in a ratio of 10:1:1). Later, all adults (except for one subsample) were mounted on slides with polyvinyl alcohol (P.V.A.) under coverslips and left for at least 24 hours to clear (Walker and Crosby 1979). A 10% subsample of adults was taken from ripe 'Redhaven' peaches in the 1985-86 season. Unmounted adults and larvae were replaced in glass vials containing A.G.A. All mounted adults were identified according to Mound and Walker (1982, 1986).

The greater portion of a thrips egg is embedded in the fleshy mesocarp just below the peach skin (exocarp). The uppermost tip of the egg is flush with the surface of the fruit (Teulon unpubl.).

The number of eggs in the fruit skin was counted after the skin was cleared and stained as follows: the skins from 10 peeled fruit were wrapped in a long strip of fine-mesh terylene so that the skin of each peach was separated. The bundle was placed in a 500-ml Pyrex beaker containing 250 ml boiling lactophenol and 25 ml 0.2% aniline blue for about 15 minutes. If two samples were ready on the same date, the procedure could be carried out with a 1000-ml beaker and twice the amount of liquid. The terylene bundles containing the peach skins were then drained and placed in cold clean lactophenol for at least 12 hours before being rinsed in water, drained and unwrapped. In clean lactophenol the aniline blue stain withdrew from the plant tissue, leaving thrips eggs stained bright blue. Care was taken to ensure the bundles were not overboiled, to prevent plant tissue break down and making observation difficult. The skins were then examined under a binocular microscope (x 10) with transmitted light. Blue thrips eggs were clearly visible within the tissue (see Plate 7). Eggs in leaf clusters were also detected in this way. Aniline blue in lactophenol is a routine technique to observe nematodes in plant tissue (Hooper 1970) and has been used to sample leafhopper eggs in apple leaves (Teulon and Penman 1986). Phenol is a nerve poison and care must be taken to avoid inhalation of the toxic fumes (Khan and Saxena 1986).

The diameter of each fruit was measured with calipers in the 1985-86 and 1986-87 seasons. Assuming that each fruit approximated a sphere, the surface area was determined so that thrips numbers could be expressed in terms of surface area.

2.1 SEASON 1984-85

PEACH

Four peach trees (var. 'Golden Queen') were sampled for adults only. On each sample date (Table 5.1) ten fruit were picked from each tree. The number of adults per peach was counted. On April 4, nine fruit remaining on the tree were picked and examined in the laboratory for the presence of larvae. Since larvae cannot be identified, they were removed from the fruit with a camelhair brush and placed in rearing cages to develop to adults (see Chapter III) which were slide mounted and identified.

2.2 SEASON 1985-86

PEACH

Five peach varieties were chosen so that their fruit harvest dates spanned the 1985-86 season. The varieties were, in order of fruit maturity, 'Red April', 'Springcrest', 'Redhaven', 'Fayette' and 'Fairtime'. On each sample date (Table 5.1) ten fruit were picked from each tree (or five from each of two trees). The numbers of thrips adults, eggs and larvae per peach were counted and infestation levels determined in terms of surface area. On January 21, ten more 'Redhaven' fruit were picked and examined in the laboratory for the presence of larvae. Live larvae were reared to adults for identification as described above.

PLATE 7. BLUE STAINED THRIPS' EGGS IN PEACH SKIN (x40 APPROX.).

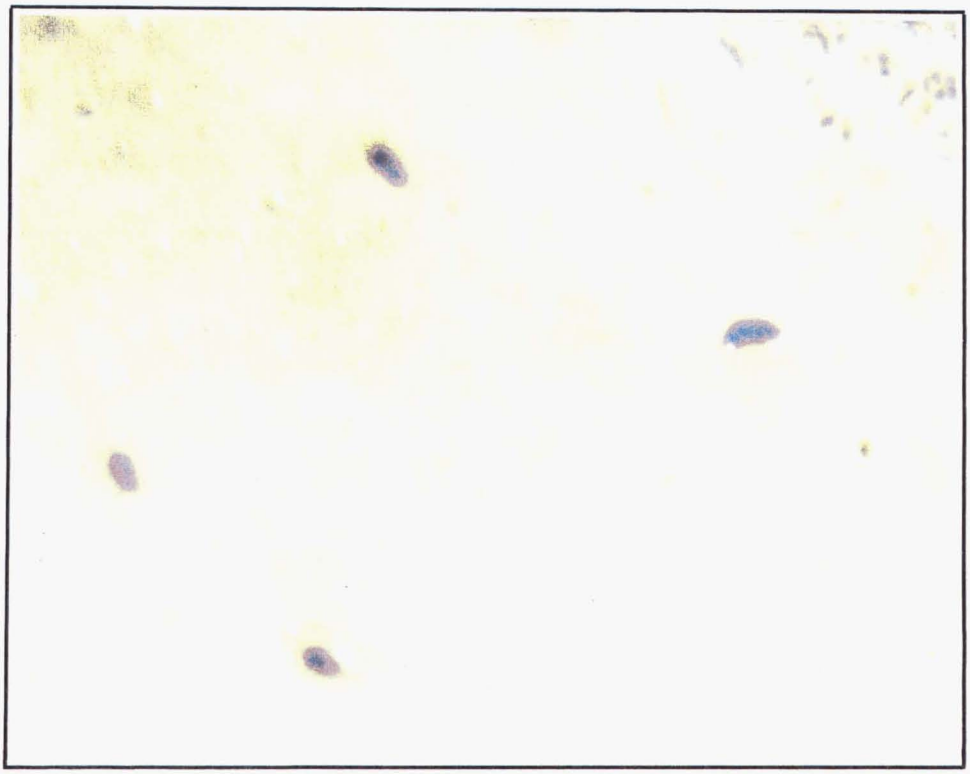
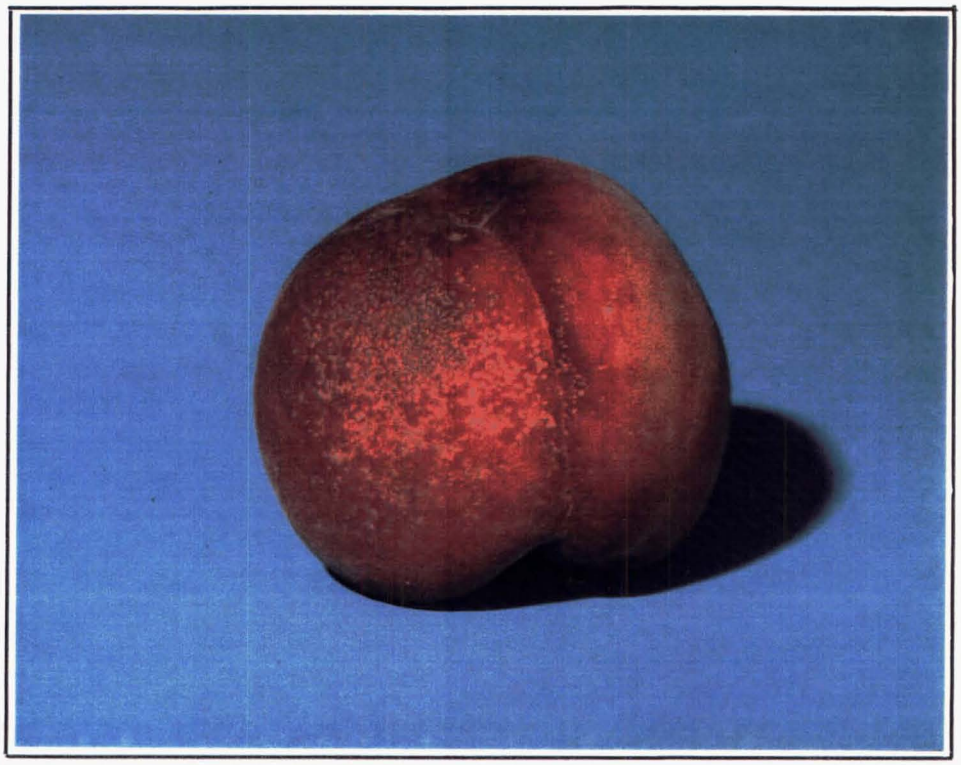


PLATE 8. THRIPS' FEEDING DAMAGE TO PEACH FRUIT.



NECTARINE AND APRICOT

Fruit from two nectarine varieties, 'Flavourtop' and 'Autumn Grand', were sampled for adults, larvae and eggs. For each variety, ten fruit (five from each tree) were picked on each sampling date (Table 5.1). Ten fruit from a 'Roxburgh Red' apricot tree were sampled at fruit harvest only for adults, eggs and larvae. The number of thrips per fruit was counted and infestation levels determined in terms of surface area. Live larvae were reared to adults for identification as described above.

2.3 SEASON 1986-87

PEACH

Fruit and leaves of one peach tree (var. 'Redhaven') were sampled for adults, eggs and larvae. At each sample (Table 5.1) ten fruit and ten leaf clusters were picked. Leaf clusters were taken from the immediate vicinity of a fruit. Adult thrips were mounted and identified.

PVC-acetate traps were used to sample pupating thrips. The traps consisted of a 100-mm length of PVC tube with an inside diameter of 190 mm placed upright on the ground. Disposable sticky acetate sheets were mounted on both sides of a clear perspex disc (dia. 200 mm) which was positioned on top of the open cylinder. These traps are designed to catch pupating larvae falling from the tree on the upper surface of the plate, and newly-emerged adults from the soil on the lower surface (Tanigoshi and Moreno 1981). Four PVC-acetate traps were placed on the ground under branches of the peach tree, one in each of four delineated quadrats. Traps were placed under the tree on January 14 and removed on February 2. Acetate sheets were changed at about six-day intervals and the traps moved to a different position within the quadrat. Thrips adults and larvae were counted from both sides of the perspex plate but were not identified.

3 RESULTS AND DISCUSSION

3.1 NUMBERS AND SPECIES PRESENT

The most common thrips species sampled from stonefruit was *T. obscuratus* (99% of all thrips identified), and most of these were females (97.7% of all thrips identified) (Table 5.2). Of other species present, only *Limothrips cerealium* was found regularly on fruit and only in small numbers. Larvae found on fruit and reared to adults were all *T. obscuratus* except for two *Thrips tabaci* and a single *Frankliniella occidentalis* each found on 'Golden Queen' peaches (Table 5.3). *Thrips tabaci* adults were seldom found on unsprayed fruit (Table 5.2) but were common on fruit in an insecticide trial in the 1986-87 season (see Chapter VIII). No *Frankliniella occidentalis* adults were found on fruit in these samples, but this species was sometimes caught in water traps inside the orchard blocks (see Appendices 10, 11, 13) and is common on nectarine fruit in California (La Rue *et al.* 1972). Martin (1987) considered that the race of *Frankliniella*

TABLE 5.2: TOTAL NUMBERS AND SPECIES OF ADULT THRIPS INFESTING THE FRUIT OF UNSPRAYED STONEFRUIT.

Variety[#]	*Thrips obscuratus* F[*]	*Thrips obscuratus* M	*Limothrips cerealium* F	Other
1984-85				
Golden Queen P	736	42	38	2 *Anaphothrips obscurus* F 1 Tubilifera
1985-86				
Red April P	866	4	1	
Springcrest P	1358	3	5	
Redhaven P	722[s]	11	4	
Fayette P	251	3	3	2 *Thrips tabaci* F
Fairtime P	55	1		
Flavourtop N	449	8	2	1 *Thrips tabaci* F
Autumn Grand N	11			
Roxburgh Red A	907	9	2	
1986-87				
Redhaven P	988	1	3	1 *Thrips tabaci* F 1 *Chirothrips manicatus* F
(leaves)	(400)	(6)	(1)	
Total	6343	82	58	8
% of total	97.7	1.3	0.9	0.1

[#] P = peach, N = nectarine, A = apricot

[*] F = female, M = male

[s] some fruit subsampled

TABLE 5.3: LARVAL THRIPS SPECIES INFESTING THE FRUIT OF UNSPRAYED STONEFRUITS.

Variety[#]	*Thrips obscuratus* F[*]	*Thrips obscuratus* M	Others
1984-85			
Golden Queen P	9	6	1 *Frankliniella occidentalis* F 2 *Thrips tabaci* F
1985-86			
Redhaven P	6	20[t]	1 unidentified M
Roxburgh Red A	2	1	
TOTAL	17	27	4

[#] P = peach, A = apricot

[*] F = female, M = male

[t] all but one micropterous

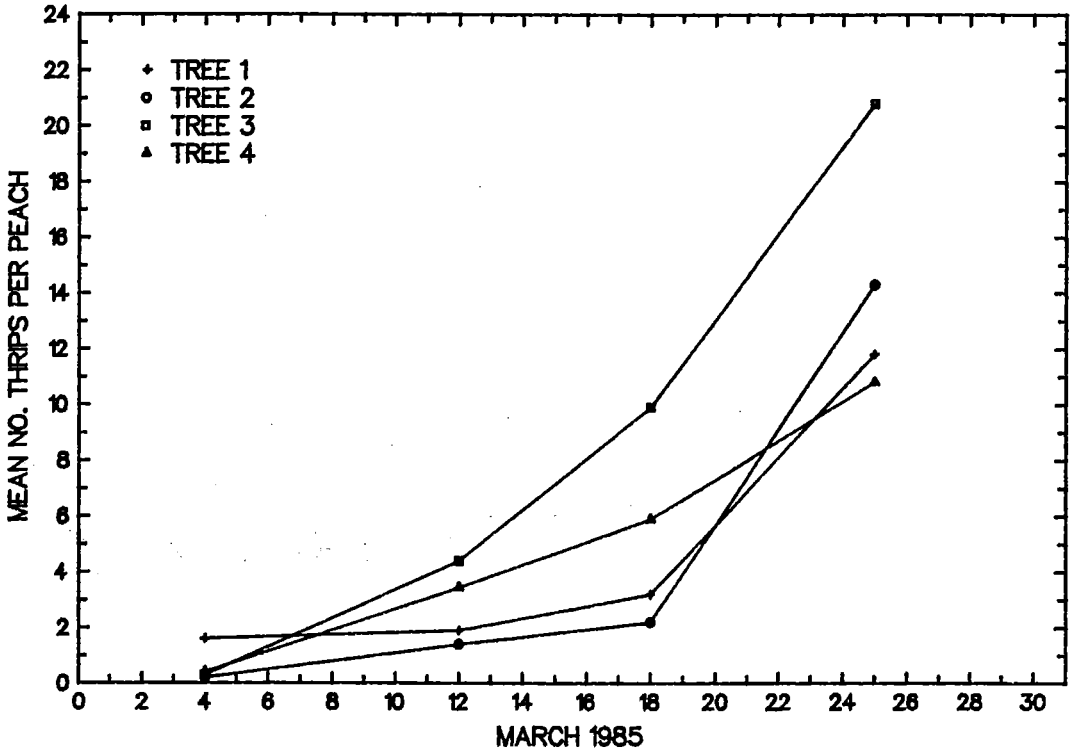
occidentalis present in New Zealand is different from that found in North America and Europe; it is regarded as a major pest in North America.

All thrips taken from peach and nectarine fruit in a newly planted orchard in Canterbury by Cruikshank (1987) were also *T. obscuratus* and most were female. Adult thrips on sprayed stonefruit were also mostly *T. obscuratus* (see Chapter VII). Therefore, in Canterbury *T. obscuratus* was clearly the most prevalent species infesting the fruit of stonefruit.

The number of thrips infesting ripening unsprayed stonefruit is expressed per unit of surface area in Figures 5.2-5.4. Figure 5.1 shows the number of adult thrips per peach for 'Golden Queen'. Infestation levels expressed as numbers of thrips per fruit for other varieties at harvest are found in Table 5.4.

Thrips adults, eggs and larvae were all common on ripe unsprayed peaches, nectarines and apricots. All stages were most numerous on ripe fruit, although each was found on peaches and nectarines some time before fruit maturity. For example, adults were found in low numbers on fruit 21 ('Golden Queen' peach), 23 ('Springcrest' peach) and 26 days ('Redhaven' peach 1985-86) before harvest. Eggs and larvae were found on fruit slightly later than adults. On 'Springcrest', eggs and larvae were found 23 and 17 days respectively before harvest, and on 'Redhaven' (1985-86) eggs and larvae were found 13 days before harvest. Similar observations have been made for thrips on stonefruit overseas. *Franklinella occidentalis*

FIGURE 5.1: ADULT THRIPS ON RIPENING 'GOLDEN QUEEN' PEACH FRUIT.



migrated onto nectarine fruit two to three weeks before picking to feed and lay eggs on maturing fruit (La Rue *et al.* 1972). *Thrips major* was most prevalent when the nectarine crop was close to harvest, laying eggs in the flesh of the fruit (Pollini and Giunchi 1979).

3.2 VARIETAL DIFFERENCES

On mature fruit thrips numbers were highest in December and January. All peach varieties sampled at this time during the 1985-86 season had similar adult numbers per unit area of skin, although egg and larval numbers for 'Redhaven' were lower than 'Red April' and 'Springcrest' (Figure 5.2). 'Red April' and 'Springcrest' fruit were smaller than those of 'Redhaven'; eggs and larval numbers on these varieties were more comparable to 'Redhaven' when expressed in terms of thrips per fruit (Table 5.4). Numbers of thrips on 'Redhaven' peaches were also high in January of the following 1986-87 season (see Figure 5.4). Varieties of peach maturing in February, March and April had significantly lower numbers of thrips adults, eggs and larvae per fruit (Table 5.4) and per unit area of skin (Figure 5.2) than fruit maturing in December and January. The number of thrips on nectarines and apricots also followed this seasonal pattern. The seasonal variation of adult thrips on ripe stonefruit reflected the broad pattern of thrips flights inside and outside the orchard. This is examined in Chapter VI.

FIGURE 5.2: THRIPS ADULTS, EGGS AND LARVAE ON RIPENING PEACH FRUIT, 1985–86 (C.I.=0.05).

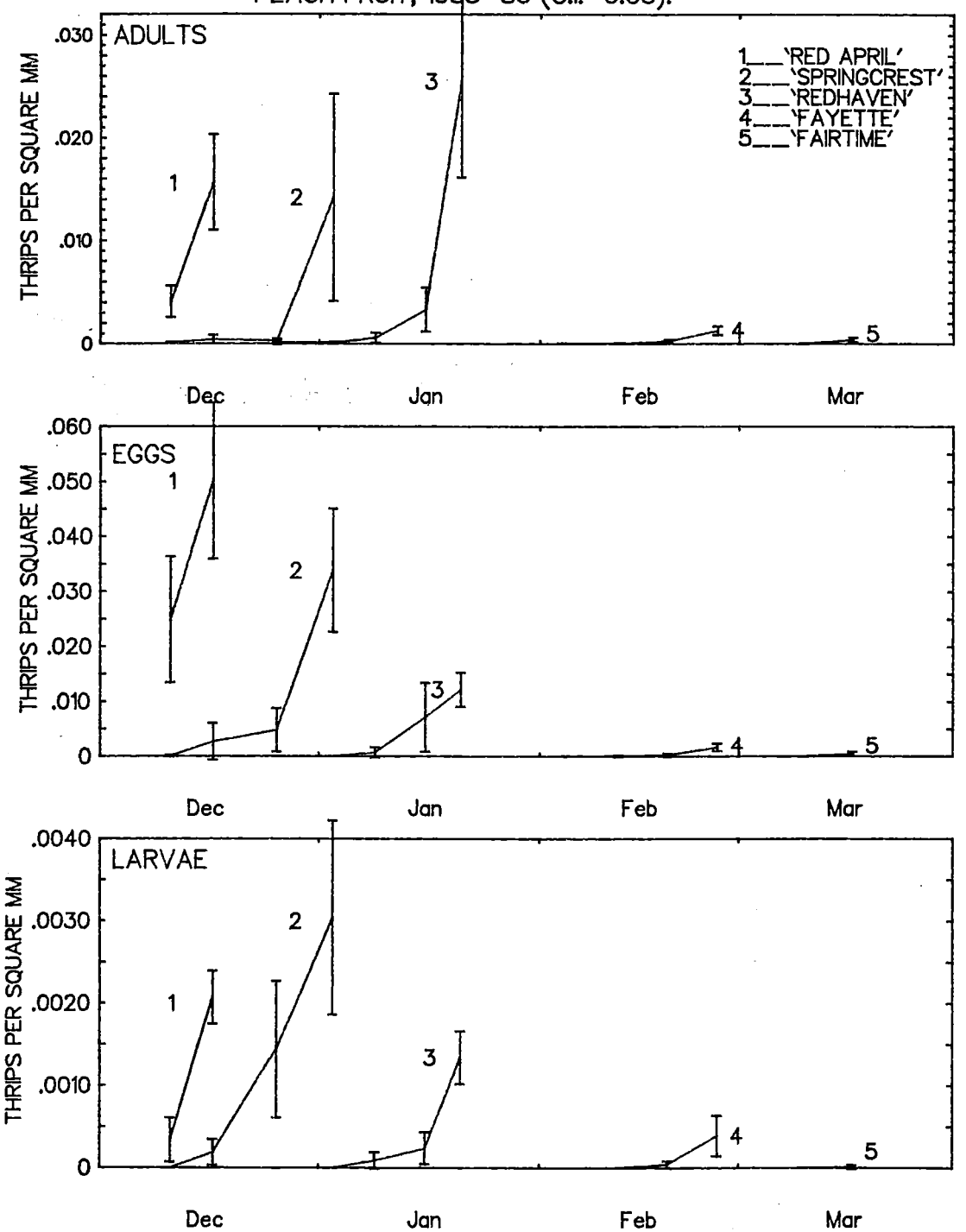


FIGURE 5.3: THRIPS ADULTS, EGGS AND LARVAE ON RIPENING NECTARINE (N) AND APRICOT (A) FRUIT, 1985–86 (CI=0.05).

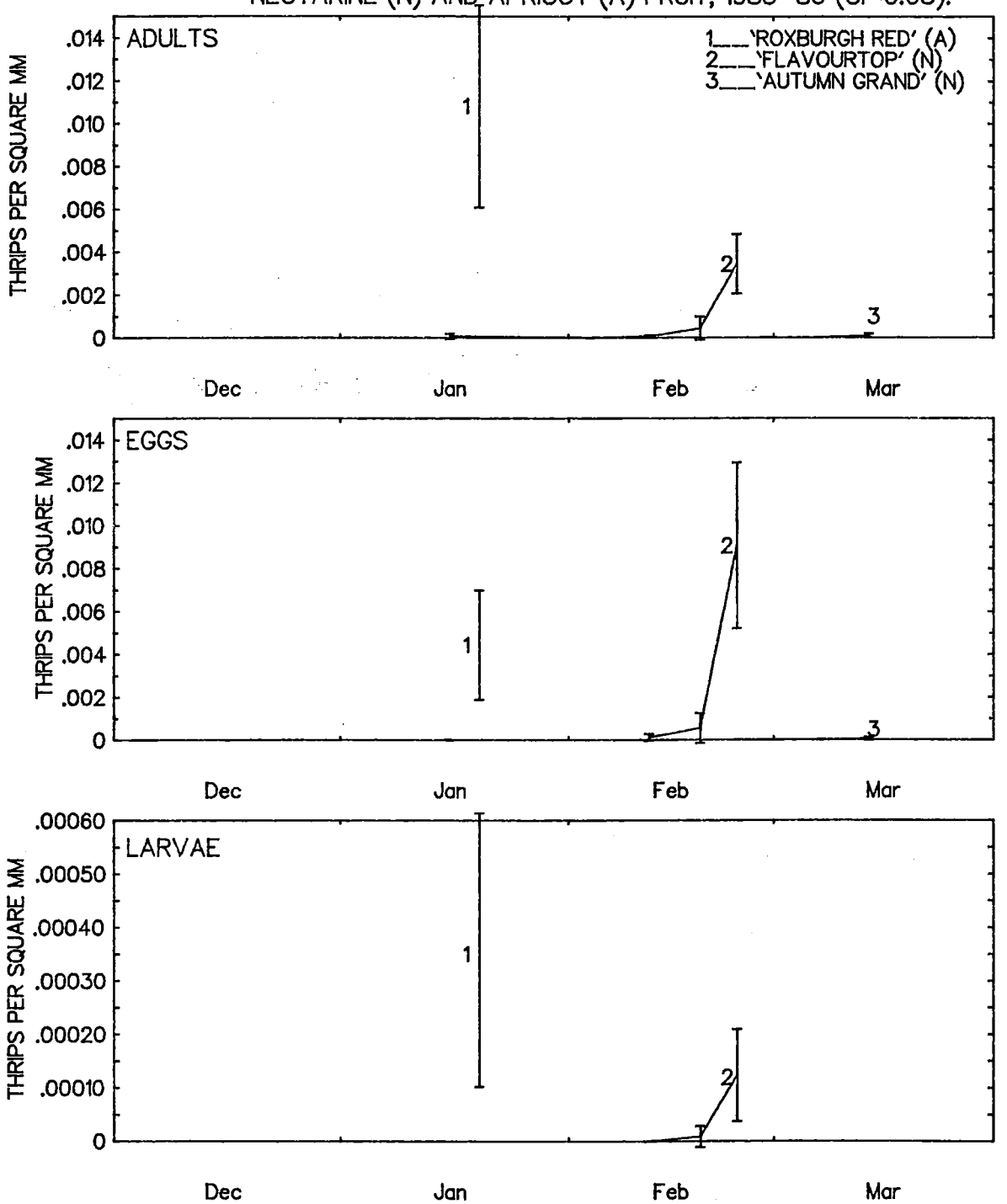


FIGURE 5.4: THRIPS ADULTS, EGGS AND LARVAE ON 'REDHAVEN' PEACH FRUIT AND LEAF CLUSTERS, 1987 (CI=0.05).

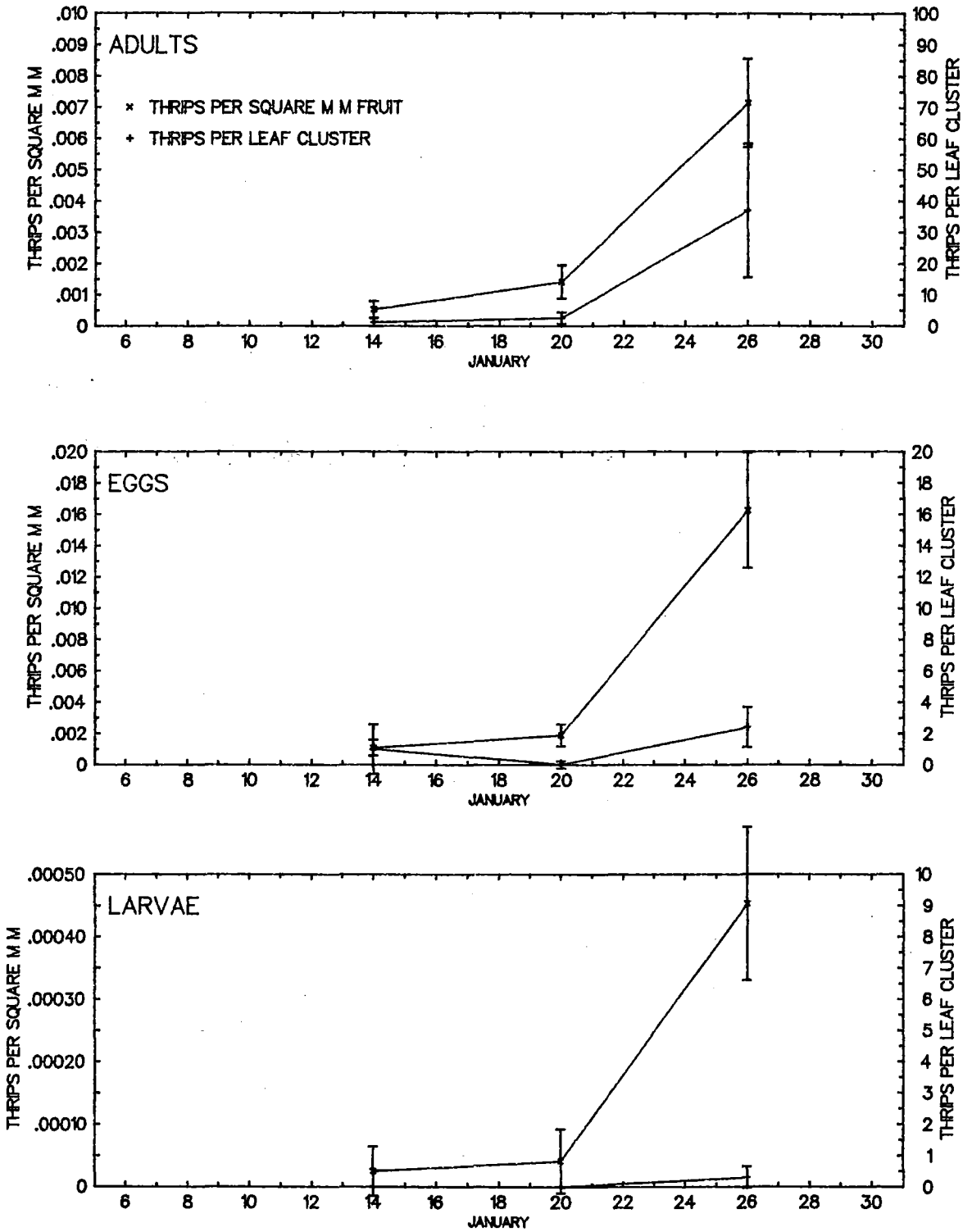


TABLE 5.4: MEAN* NUMBER OF THRIPS PER FRUIT ON UNSPRAYED STONEFRUIT AT HARVEST.

Variety#	Adults		Eggs		Larvae	
	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.
1984-85						
Golden Queen P	13.5	13.0				
1985-86						
Red April P	67.1	28.24	211.8	83.6	8.7	1.7
Springcrest P	131.3	139.6	315.7	139.6	30.0	19.2
Redhaven P	350.8	218.5	164.2	73.7	17.2	5.3
Fayette P	21.0	10.4	26.3	15.0	6.2	5.8
Fairtime P	5.7	4.1	6.2	7.6	0.2	0.3
Flavourtop N	40.0	23.5	107	63.8	1.2	1.2
Autumn Grand N	1.1	1.5	0.7	1.3	0.0	-
Roxburgh Red A	91.7	57.3	38.3	31.2	3.1	3.2
1986-87						
Redhaven P	81.8	24.6	5.2	2.0	185.2	55.6

* all means of 10 fruits except for 'Golden Queen'

\# P = peach, N = nectarine, A = apricot

Thrips numbers on ripe stonefruit were nearly always higher on peaches than on apricots for fruit harvested at similar times. Apart from adults on 'Flavourtop' nectarines, thrips adults, eggs and larvae were more common on 'Fayette' peaches than 'Flavourtop' nectarines, on 'Fairtime' peaches than 'Autumn Grand' nectarines, and on 'Redhaven' peaches than 'Roxburgh Red' apricots. Thrips adult numbers on fruit varied from day to day in relation to ambient humidity and sunshine conditions (Pollini and Giunchi 1979, Ellis pers. comm.). It was not possible to make a direct comparison between the number of thrips on different stonefruit types, as they had different dates of maturity. However, Cruikshank (1987) found markedly more adults on peaches than on nectarines in a newly-planted orchard in Canterbury, and Tomkins (1985) also noted that adult thrips prefer peaches to other stonefruit.

Thrips' apparent preference for peach over nectarine is probably related to structural differences of the skin. Hairy peach skins may retain more moisture close to the fruit' surface than the smooth-skinned nectarines. Low humidity is known to reduce oviposition in thrips (Putman 1942) and may limit larval

survival in hot conditions. Differences in fruit colour and aroma between peaches, nectarines and apricots may also be important (see Chapter VII).

3.3 DISTRIBUTION ON FRUIT

With high levels of infestation (e.g., at harvest) adults, eggs and larvae were found all over the fruit. When thrips numbers were lower, adults and larvae tended to be found in the more protected areas of the fruit such as around the receptacle where old flower parts sometimes remained, in cracks in the fruit and in the slight dip at the distal apex. The distribution of eggs at low infestation levels was not determined, but was likely to be similar to that of adults and larvae. Numerous eggs of *Thrips major* were laid in the peduncle zone of nectarine fruit (Pollini and Giunchi 1979).

Although it has been found that larvae can reach maturity on a diet of peach fruit in the laboratory (see Chapter III), it is doubtful that many of the eggs laid in fruit in the field survived to maturity. Most eggs were laid in fruit in the week before harvest. At 20^{o}C egg development takes about four days (Table 3.4) and larval development on fruit between seven and nine days (Table 3.2). Therefore most eggs and larvae have insufficient time to develop before the fruit is picked. The typical habitat for larval development is within the protected and humid environment of flowers (see Chapter IV). The surface of fruit does not provide the same degree of protection as flowers, and about half the larvae examined on fruit were dead. Many of the larvae sampled on fruit were found in surface irregularities on the fruit where humidity would be greater. Similarly, larvae of *Frankliniella occidentalis* and *Thrips major* sought protected areas at points of contact of the fruit with branches or leaves (La Rue *et al.* 1972, Pollini and Giunchi 1979). There are few of these protected positions on fruit and this may explain the high larval mortality.

Large numbers of *T. obscuratus* females were found on leaf clusters picked close to ripe fruit on 'Redhaven' peaches in 1986-87. There were few eggs in and virtually no larvae on the leaves (Figure 5.4). It is evident that adults prefer to oviposit on fruit. At harvest there were 2.3 eggs per female on fruit compared to 0.065 eggs per female in the leaves. Eggs have also been found in nectarine leaves by McLaren (1982), but their presence along with larvae and adults appears to be incidental and due to the close proximity of the ripening fruit. A possible exception should be mentioned here. *Thrips obscuratus* adults and unidentified larvae were observed inside leaves affected by the disease leaf curl (*Taphrina deformans*) late in the flowering period. The tightly curled leaves may provide suitable thigmotaxic stimuli and adequate protection and nutrition for thrips oviposition and larval development.

3.4 SOURCE OF INFESTATION

Many thrips adults were trapped on the upper surface of the PVC-acetate traps placed under an infested 'Redhaven' peach tree in the 1986-87 season (Table 5.5). These were presumably thrips flying or dropping out of the canopy. A few adult thrips were trapped on the underside of the perspex disc. Most were pale and small, possibly *Thrips tabaci*, and may have been on the ground before the traps were positioned, or newly-emerged adults that were pupating in the soil before trap placement. Only 2 larvae were trapped on the upper surface of the four traps during the sampling period. This indicated that few

TABLE 5.5: MEAN NUMBER OF ADULT AND LARVAL THRIPS CAUGHT ON PVC-ACETATE TRAPS PLACED BENEATH A PEACH TREE.

	Upper surface		Lower surface	
	$\bar{x}$	S.D.	$\bar{x}$	S.D.
20/1/87				
Adults	102.7	47.68	2.25	1.09
Larvae	0		0.25	0.43
26/1/87				
Adults	427.0	55.7	8.25	3.7
Larvae	0		0	
2/2/87				
Adults	284.8	47.12	18.25	16.31
Larvae	0.5	0.5	0	

larvae were dropping from the tree to pupate and is supporting evidence that few *T. obscuratus* larvae reach maturity on fruit.

Adults were found on stonefruit from December to April. Initial sources of infestation were probably nearby flowers. As few larvae reached maturity on ripe fruit, flowers must also have been the source for thrips infesting fruit later in the season. This was verified by the high number of eggs in the fruit. On ripe fruit there were commonly between 1-3 eggs per adult female. In the laboratory it has been shown that such high rates of oviposition occur only after pollen feeding and not on diets of peach fruit (Figure 3.5). Therefore the adults found on fruit must have recently migrated from flowering hosts inside or outside the orchard. Further evidence that thrips were continually moving into the orchard is given in Chapter VI. Insecticide applications within the orchard blocks had a negligible effect on the number of thrips flying in the orchard.

There may be several reasons why *T. obscuratus* and other adult thrips are attracted to ripe stonefruit. La Rue *et al.* (1972) considered that *Frankliniella occidentalis* may have been attracted to nectarine fruit either by colour changes of the fruit or the characteristic odour that becomes apparent shortly before picking. This will be examined in Chapter VII.

3.5 ECONOMIC CONSIDERATIONS

The infestation of ripe stonefruit by *T. obscuratus* has important economic implications. Feeding damage leads to the typical discolouring, bleaching, and speckling associated with thrips on other vegetation (see Plate 8). Feeding damage is especially noticeable in areas on the fruit where thrips are

commonly found, such as the distal apex and around the receptacle. Only on severely infested fruit, such as unsprayed peaches in December and January in Canterbury, does feeding damage become obvious. Otherwise the main economic problem is the contamination of export fruit by thrips adults, eggs and larvae. Currently there is a 1% tolerance for live thrips on stonefruit entering Australia and a 2% tolerance for the rest of the world (Anon. 1988a).

Eradication of adult thrips may be achieved with control measures immediately before harvest for varieties showing low thrips numbers and hence little fruit damage, such as those ripening in February, March and April in Canterbury. For stonefruit maturing in December and January (e.g., 'Red April', 'Springcrest' and 'Redhaven') when thrips infestation was high, the length of protection may have to be extended to minimise feeding damage. Furthermore, research reported in this chapter has shown that eggs were laid in fruit up to three weeks before local market maturity. Some of these eggs had time to hatch, and larvae were found on the fruit. Larvae and possibly eggs also constitute thrips contamination on export fruit, and eggs may hatch after the fruit is picked and has reached its market. Where insecticide residues on the fruit are low these larvae may mature to adults. The period of protection therefore has to cover the period when thrips are laying eggs in the fruit. Fruit are picked several days earlier for export than for local markets, but the period when thrips ovipostion occurs on export fruit may still exceed two weeks before picking. Controls must either stop egg laying or ensure larval death at egg hatch. The merits of various insecticide controls to reduce thrips infestation on ripe stonefruit will be examined in Chapter VIII.

4 SUMMARY

Thrips adults and larvae sampled from ripe stonefruit were almost all *T. obscuratus*. Adults were almost entirely female.

Thrips adults, eggs and larvae were all common on ripe unsprayed stonefruit, including peaches, nectarines and apricots. Thrips were most numerous on ripe fruit, although they were found on fruit up to three weeks before harvest for the local market.

Thrips numbers were highest on peach varieties ripening during December and January and lowest on varieties ripening during February, March and April. Thrips numbers on nectarines and apricots followed this seasonal pattern.

Thrips numbers were higher on peaches than apricots and nectarines. The presence of thrips on peach leaves appeared to be incidental and due to the close proximity of the ripening fruit.

Thrips were found in protected positions on the fruit at low infestation levels but covered the fruit at high levels of infestation.

Sources of thrips infestation were probably flowers in the vicinity of the orchard. It was unlikely that many larvae that hatched from the fruit reached maturity.

The important economic implications from the infestation of ripe stonefruit by *T. obscuratus* are directly related to feeding damage and especially to contamination of export fruit with thrips adults, eggs and larvae.

CHAPTER VI

THE SEASONAL ABUNDANCE AND ACTIVITY OF THE NEW ZEALAND FLOWER THRIPS

1 INTRODUCTION

An understanding of the seasonal abundance and activity of an insect pest is essential for pest management, as it helps to determine the need for and timing of controls (Anon. 1969). Cropping may be manipulated to avoid critical periods, and understanding the factors causing population fluctuations may provide insights for the control of pests.

Factors that influence population abundance in thrips include: the initial population size, immigration and emigration, weather, the availability of hibernation and breeding sites and parasitism and predation (Lewis 1973). So far no research has identified the important factors that regulate *T. obscuratus* populations.

Peak population numbers of the New Zealand flower thrips were found in November in Central Otago and Nelson (McLaren 1981, Martin 1983) and in January in Canterbury (Penman *et al.* 1982). In Canterbury, adults and larvae were present in stonefruit flowers during spring (Chapter IV) and on fruit from December to April (Chapter V). Peak thrips numbers on ripe stonefruit occurred in January-February in Central Otago (McLaren 1983) and December-January in Canterbury (Chapter V). *T. obscuratus* is probably multi-voltine, as adults and larvae were found on plants throughout the year (Mound and Walker 1982, see Chapter IV) and adults were active in midwinter in Central Otago (McLaren 1985).

Methods for estimating population density fall into two groups: absolute and relative. Absolute methods estimate as densities per fixed unit, e.g., number per unit volume of air, whereas relative methods estimate density in terms of a qualitative unit, e.g., number per trap. Relative estimates are not easily converted to absolute estimates, but the sampling methods are cheap and simple and usually provide enough data to compare population density between different times and places (Anon. 1969).

It is easier to sample aerial than terrestrial populations of thrips, as the air is homogeneous and the insects easily separated from it (Lewis 1973). Sticky and water traps have proved the most popular relative methods for estimating population densities of thrips. Sticky traps have often been preferred to other sampling methods because of their low cost and ease of handling, and they provide a continuous record of insect abundance and activity (Taboada *et al.* 1975, Purrell and Elkinton 1980). Water traps are less precise than sticky traps, especially above vegetation where wind is faster (Lewis 1959), but thrips removal for identification is much easier.

Some species of thrips are attracted to certain colours. Black traps should be used to avoid differential attraction when studying the specific structure of a fauna (Lewis 1973), but coloured traps can

be used to maximise the catch of a particular thrips species. White was found to be most effective for sampling *T. obscuratus* adults (see Chapter VII).

The aims of this part of the study were to establish the seasonal abundance and activity of *T. obscuratus* in Canterbury and the factors influencing this. Sticky board and water trap samples were taken inside stonefruit blocks to correlate thrips abundance with stonefruit flower and fruit phenology. Samples were taken from outside stonefruit blocks to indicate the abundance of thrips in an environment less affected by the presence of stonefruit and insecticide applications. Thrips flights were also sampled throughout winter and the reproductive capacity of *T. obscuratus* females during this time was determined. Seasonal variation in temperature and soil moisture and the availability of host plants was examined to correlate with the thrips' seasonal abundance.

2 MATERIALS AND METHODS

2.1 THRIPS FLIGHTS

All sampling took place in the Lincoln College Horticultural Research Area (see Appendix 5). Two stonefruit variety blocks were sampled separately. Block 1 consisted of many different varieties of peaches, nectarines, apricots and plums. Most trees were planted in 1979 and 1980 but were being progressively removed during the time of this study. Block 2 consisted of only peach and nectarine varieties, which were planted in 1984 and 1986. Detailed descriptions of both blocks are found in Appendix 5, along with the insecticide spray programmes and position of traps. Traps positioned outside stonefruit blocks were about 70 m from the nearest stonefruit trees in fields with ground cover consisting of various grasses, clover (*Trifolium repens* L.) and a number of weeds (see Appendix 5).

Sticky boards and water traps were used to sample adult thrips flights. Sticky boards were hardboard rectangles (230 x 190 x 5 mm) painted white (White Superseal, Dulux New Zealand Ltd). The spectral reflectance is found in Figure 7.1. They were hung at a height of 1.7 m inside the canopy of nectarine trees. Both sides of each board were covered with 'Tack-trap' (Animal Repellents Inc. Griffin) or a constituted sticky substance (Appendix 8). Both supply a permanent sticky surface for trapping light-weight insects. A single clear 'mylar' (DuPont, Circleville) acetate sheet (210 x 140 mm) was placed on each side of the board and covered with a further layer of sticky substance. Servicing the sticky boards involved removing the acetate sheets and placing them on sheets of computer paper which were rolled into a cylinder and stapled at both ends to secure them. A clean acetate sheet was then replaced on the board and covered with the sticky substance. In the laboratory the acetate sheets were unrolled and examined for thrips under a binocular microscope. No attempt was made to identify thrips because of the time and effort required. This was one of the main reasons for replacing sticky boards with water traps in the following seasons.

Water traps were 2-litre plastic containers (170 x 170 x 85 mm) (Probit Industries Ltd. Auckland) painted white (White Superseal, Dulux New Zealand Ltd.). The traps were placed on 1.7 m poles and constructed to allow easy removal (see Plate 5). Inside the orchard, water traps were positioned between trees of the same row. Each trap contained about one litre of water, a few drops of formaldehyde to prevent algal and fungal growth and detergent to facilitate thrips sinking in the water. White painted netting (mesh size 20 x 20 mm) was used to prevent the entry of leaves and birds. When thrips numbers were large (e.g., during summer) the whole water trap was removed from the pole and replaced by another, and thrips were extracted with a pipette in the laboratory. During colder months (e.g., winter) the few thrips trapped were removed in the field.

All adult thrips were placed in vials containing A.G.A. (60% ethanol, glycerine and acetic acid in the ratio of 10:1:1) and were later were mounted on slides (except for subsamples) with polyvinyl alcohol (P.V.A.) under coverslips and left to clear for at least 24 hours (Walker and Crosby 1979).

Total thrips numbers were estimated for both sticky and water traps. All thrips were identified from the water traps except on sampling dates when total thrips numbers exceeded 100 per trap per week. On these occasions 25% subsamples were mounted for indentification. Thrips were identified according to Mound and Walker (1982 and 1986).

Table 6.1 gives details of thrips trapping including type and number of traps, time of year, temporal extent of trapping and interval between samples. Although the interval between samples varied, the period of trapping was about one week for each sample. In the 1985-86 summer, samples were taken weekly until 23 January after which they were taken fortnightly. In the 1986-87 summer, samples were taken weekly until 27 November after which they were taken fortnightly.

2.2 HOST SEASONALITY

Floral hosts of *T. obscuratus* larvae found in Canterbury (Table 4.1) were grouped according to month of sample to show the seasonal occurrence of known breeding hosts. Only floral hosts were included, as these fulfil the requirements for thrips development and breeding. Flowering and harvest dates for selected stonefruit varieties in the Lincoln College Horticultural Research Area were established.

2.3 METEOROLOGICAL MEASUREMENTS

Meteorological data, including daily maximum and minimum temperatures, rainfall and pan evapotranspiration values, were taken from the Lincoln College Meterological Station situated close to the Lincoln College Horticultural Research Area (see Appendix 4).

Maximum and minimum temperatures and the lower threshold of development for a generation (egg to egg) (Table 3.6) were used to estimate the length and number of generations for the three seasons of thrips sampling by day-degree accumulation (Arnold 1960). As stonefruit constitute some of the earliest-flowering hosts for *T. obscuratus* in spring, day-degree accumulations were initiated at the pink stage of peach flower development for each season. The period of development for a generation (egg to egg) was

TABLE 6.1: DETAILS OF THRIPS FLIGHT TRAPPING IN THE LINCOLN COLLEGE HORTICULTURAL AREA.

		No. Sticky Boards	No. Water Traps	Sampling Commence	Sampling Finish	Sampling Interval
BLOCK 1						
SP/SU/AU*	1984-85	6		6 Aug	2 May	fortnightly
WI	1985		6	2 May	25 Jul	weekly
SP/SU/AU	1985-86		6	21 Aug	17 Apr	weekly/fortnightly
BLOCK 2						
SP/SU/AU	1985-86		6	21 Aug	17 Apr	weekly/fortnightly
WI	1986		6	2 May	22 Aug	fortnightly
SP/SU/AU	1986-87		6	28 Aug	16 Apr	weekly/fortnightly
WI	1987		6	4 May	28 Aug	fortnightly
OUTSIDE						
SP/SU/AU	1985-86		6	3 Oct	17 Apr	monthly
SP/SU/AU	1986-87		6	11 Sep	2 Apr	monthly
WI	1987		6	4 May	11 Aug	monthly

* SP = Spring, SU = Summer, AU = Autumn, WI = Winter

completed when the thermal constant K was reached (Table 3.6). *T. obscuratus* pupate in the soil and temperatures were measured from a standard Stevenson screen. The relationship between screen and soil temperature is not clear, and pupation accounts for about 25% of the length of a generation (see Table 3.4). Therefore these measurements give only a rough estimate of generation time, but they are useful as they indicate relative differences in development time throughout the season.

The level of soil moisture was determined using the following model:

$$SM_i = SM_{i-1} + R \times F \times EP$$

when $SM_i < 0$ then $SM_i = 0$
and when $SM_i > 100$ then $SM_i = 100$

where SM = soil moisture (mm of water per metre of soil)
R = rainfall
F = pan factor (0.8 for summer, 0.6 for winter, otherwise 0.7)
EP = pan evapotranspiration.

The model was seeded during a period of soil saturation, assuming a field capacity of 100mm water per metre depth in soil. This model has given good descriptions of soil moisture levels around Lincoln College (Cherry, N. pers. comm.)

2.4 OVIPOSITION ACTIVITY

During the winter of 1985, adult female thrips were collected at weekly intervals from flowers of garden roses (*Rosa* sp.) (29/4 to 12/6) and winter sweet (*Chimonanthus praecox* (L.) Link.) (25/6 to 24/7). In the laboratory thrips were kept under optimum conditions for egg laying at both a long day photoperiod (16L:8D) and a photoperiod equivalent to that prevailing in the field on the day they were sampled (range 10.15L:13.45D to 9L:15D). On each sample date, between eight and ten female thrips were placed in each of two rearing cages supplied with 10% sucrose and Iceland poppy (*Papaver nudicaule* L.) pollen in humid plastic boxes inside controlled temperature cabinets at 20°C (see Chapter III). After 48 hours the eggs in the sucrose were counted and adults were removed, killed and identified.

3 RESULTS AND DISCUSSION

3.1 SPECIES COMPOSITION

The mean numbers of flying thrips caught on sticky boards and in water traps inside and outside stonefruit blocks from September 1984 to August 1987 are shown in Figures 6.1 to 6.15. For water samples (May 1985 onwards) *T. obscuratus* females and males were distinguished from other thrips species. *Thrips tabaci* was numerous in most samples, and during summer was the most abundant thrips species caught both inside and outside orchard blocks. *Limothrips cerealium* was more abundant than any other thrips for a short period in October, and was found throughout the year in appreciable numbers. *Haplothrips niger* was common in November and December. Other thrips that were consistently trapped included *Thrips australis, Chirothrips manicatus* and *Ceratothrips frici.* Individual trap catches and thrips species are listed in Appendices 9-15. This discussion focuses on *T. obscuratus.*

3.2 ABUNDANCE WITHIN ORCHARD BLOCKS

A broad pattern of the seasonal abundance of *T. obscuratus* was apparent from the water trap samples. Thrips numbers were low in spring (Figures 6.2-6.6) and increased gradually during early summer to peak in midsummer. Numbers suddenly declined in mid to late January followed by a period of moderate to low numbers throughout late summer and autumn (Figures 6.7-6.11). Thrips numbers were lowest throughout winter (Figures 6.12-6.15). This seasonal pattern was reflected by the total number of other thrips species and also by total thrips numbers trapped on sticky boards in the 1984-85 season when thrips species were not differentiated (Figure 6.1). A similar pattern was found by Cruickshank (1987) for *T. obscuratus* numbers caught in water traps between September and April in a newly-planted Canterbury stonefruit orchard in the 1985-86 season.

Floral breeding hosts for *T. obscuratus* were found throughout most of the year, but they were more plentiful in spring and early summer and comparatively scarce during winter (Figure 6.16). Although this list indicates the seasonal occurrence of breeding host species for *T. obscuratus* the total number of breeding sites available is also a function of the abundance of any given host species.

The number of *T. obscuratus* adults trapped throughout winter (May to August) may have been influenced by several factors. Water traps sampled flying thrips, and maximum daily temperatures throughout winter were seldom above the flight-takeoff threshold of 15°C established in Chapter IV (see Figures 6.13b, 6.14b, 6.15b). During the winter of 1987 the maximum daily temperature exceeded 15°C only once between 15 June and 1 August. No thrips were caught within the orchard during this time (Figure 6.14). When temperatures did exceed 15°C during winter the numbers of *T. obscuratus* adults caught were still low, both inside and outside the orchard. This was probably an accurate indication of a low population level during winter due to the scarcity of breeding host plants (Figure 6.16), slow development rates and the possible lethal effects of low temperatures. The lower lethal temperature for *T. obscuratus* has not been determined. Andrewartha and Steele (1934) also found that temperature was the most important factor operating against the activity of *Thrips imaginis* adults during the winter.

In Central Otago flowering plants are scarce throughout winter so that reproduction probably ceases. There *T. obscuratus* adult females have been found sheltering in the seedheads of the introduced weed, *Verbascum thapsus* L. in May, June and July (McLaren 1985). It has been demonstrated in the laboratory that *T. obscuratus* adults live for long periods at low temperatures (up to 34 weeks at 10°C, see Table 3.4), sufficient to survive the winter months.

During spring (September, October, November) temperatures increased and the flight take-off threshold was often exceeded (Figures 6.2b, 6.4b), so that thrips could fly from overwintering hosts to the many plant species that flowered over this time (Figure 6.16). Initially, low temperatures limited the speed of development and thus the generation time. The first generation of thrips from eggs laid at stonefruit pink was not completed until about early November (Table 6.2), so that thrips numbers did not build up quickly in spring.

As summer progressed many breeding hosts were available (Figure 6.16) and temperatures increased, so that flight was not restricted and generation times were much quicker (Table 6.2). During November and December thrips numbers increased and their numbers approximated the logistic growth curve common for insects in optimum conditions (Krebs 1972).

FIGURE 6.1: MEAN NUMBER OF ADULT THRIPS CAUGHT ON STICKY BOARDS, BLOCK 1, 1984–85, WITH INSECTICIDE APPLICATIONS, MAXIMUM AND MINIMUM TEMPERATURES AND SOIL MOISTURE

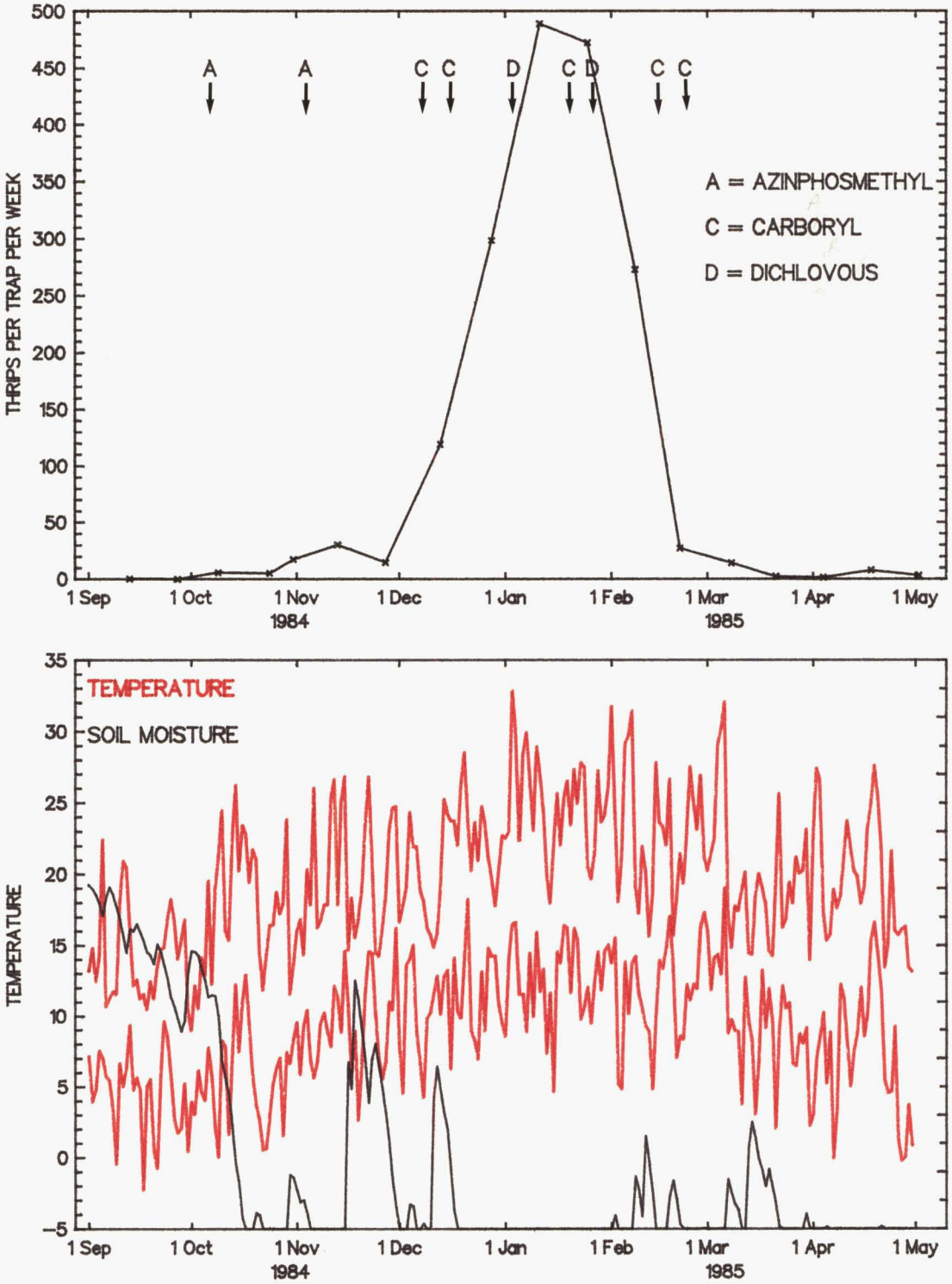
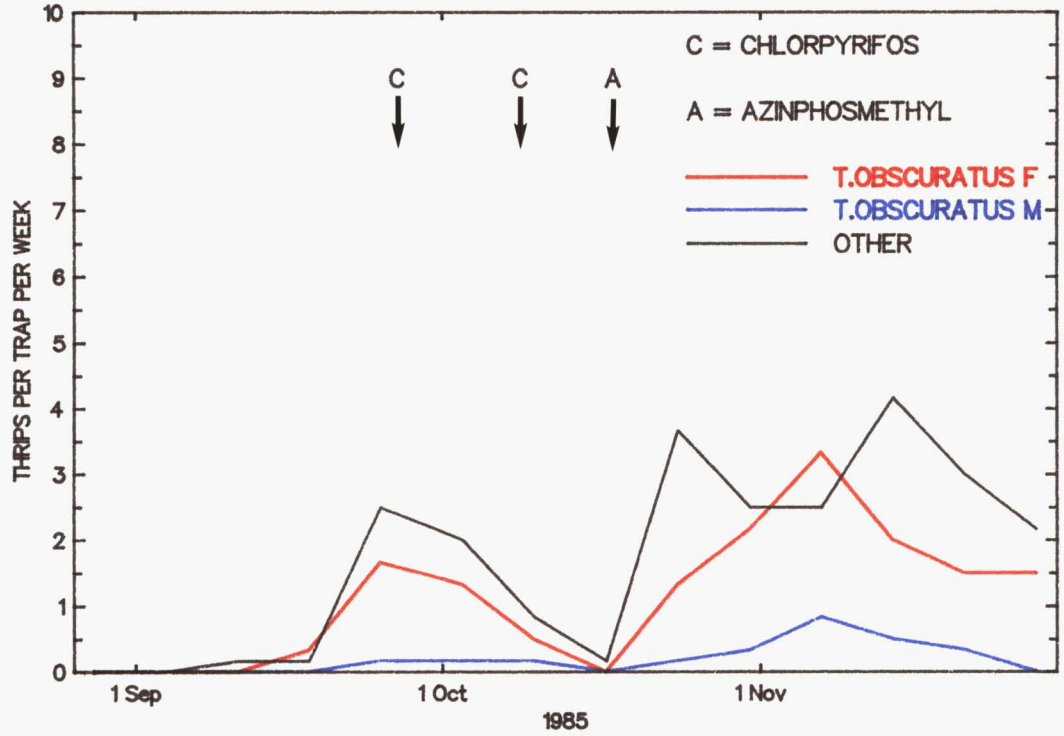


FIGURE 6.2: MEAN NUMBER OF ADULT THRIPS CAUGHT IN WATER TRAPS, BLOCK 1, SPRING 1985, WITH INSECTICIDE APPLICATIONS, MAXIMUM AND MINIMUM TEMPERATURES AND SOIL MOISTURE



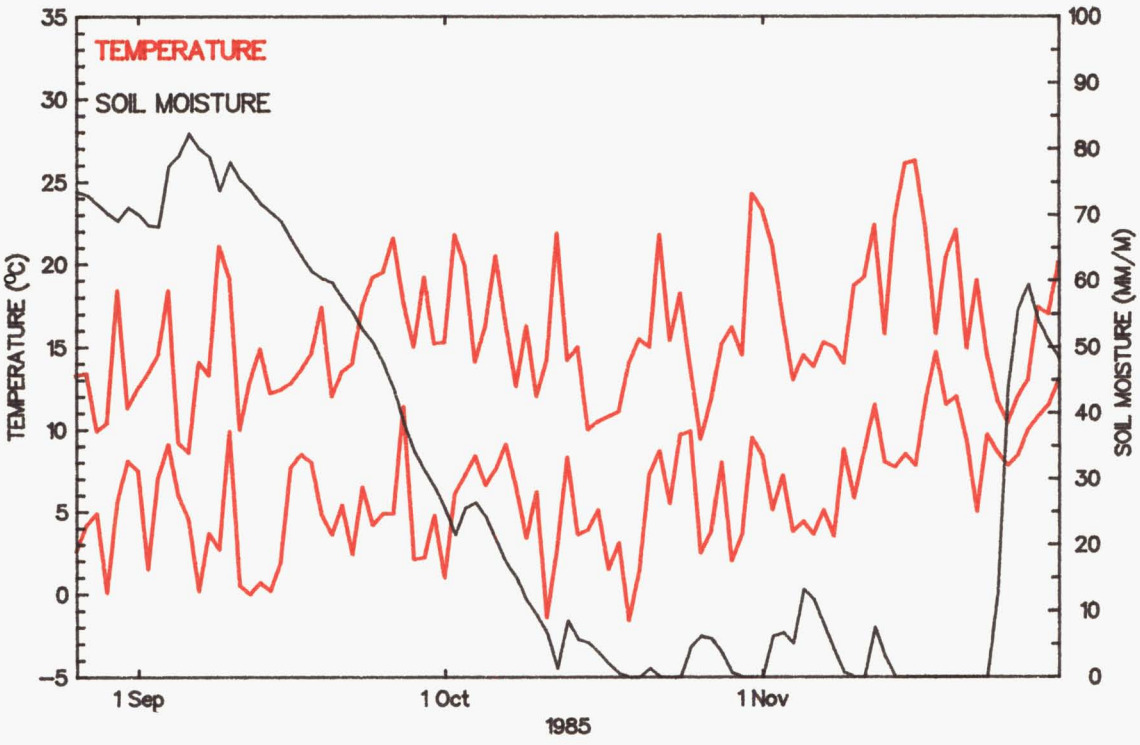


FIGURE 6.3: MEAN NUMBER OF ADULT THRIPS CAUGHT IN WATER TRAPS, BLOCK 2, SPRING 1985, WITH INSECTICIDE APPLICATIONS (↓).

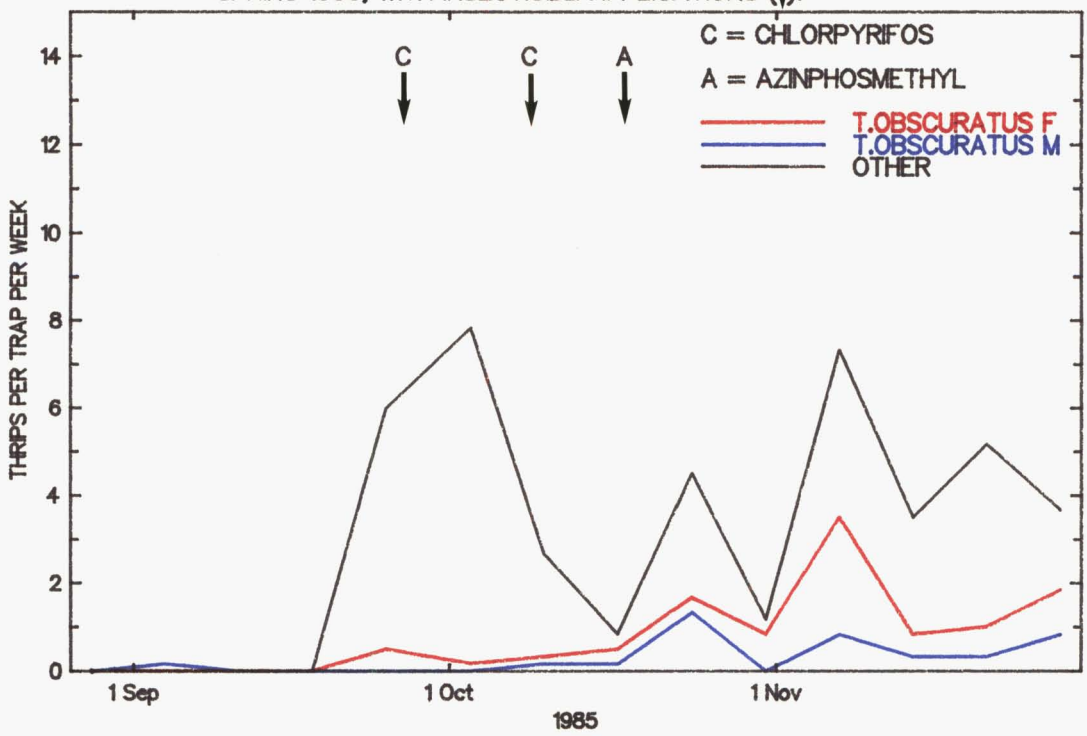


TABLE 6.2: DATE FOR COMPLETION OF A GENERATION (EGG-EGG) FOR THE N.Z. FLOWER THRIPS BASED ON DEGREE-DAY ACCUMULATIONS INITIATED AT STONEFRUIT FLOWERING (PINK).

		Date for Completion of Generation (Egg-Egg)								
Season	Pink	1	2	3	4	5	6	7	8	9
1984-85	24/8	27/10	2/12	31/12	22/1	17/2	17/3	21/4	1/8	-
1985-86	26/8	1/11	12/12	7/1	31/1	25/2	1/4	13/5	-	
1986-87	10/9	8/11	18/12	12/1	4/2	8/3	16/4	18/6		

FIGURE 6.4: MEAN NUMBER OF ADULT THRIPS CAUGHT IN WATER TRAPS, BLOCK 2, SPRING 1986, WITH INSECTICIDE APPLICATIONS (↓), MAXIMUM AND MINIMUM TEMPERATURES AND SOIL MOISTURE.

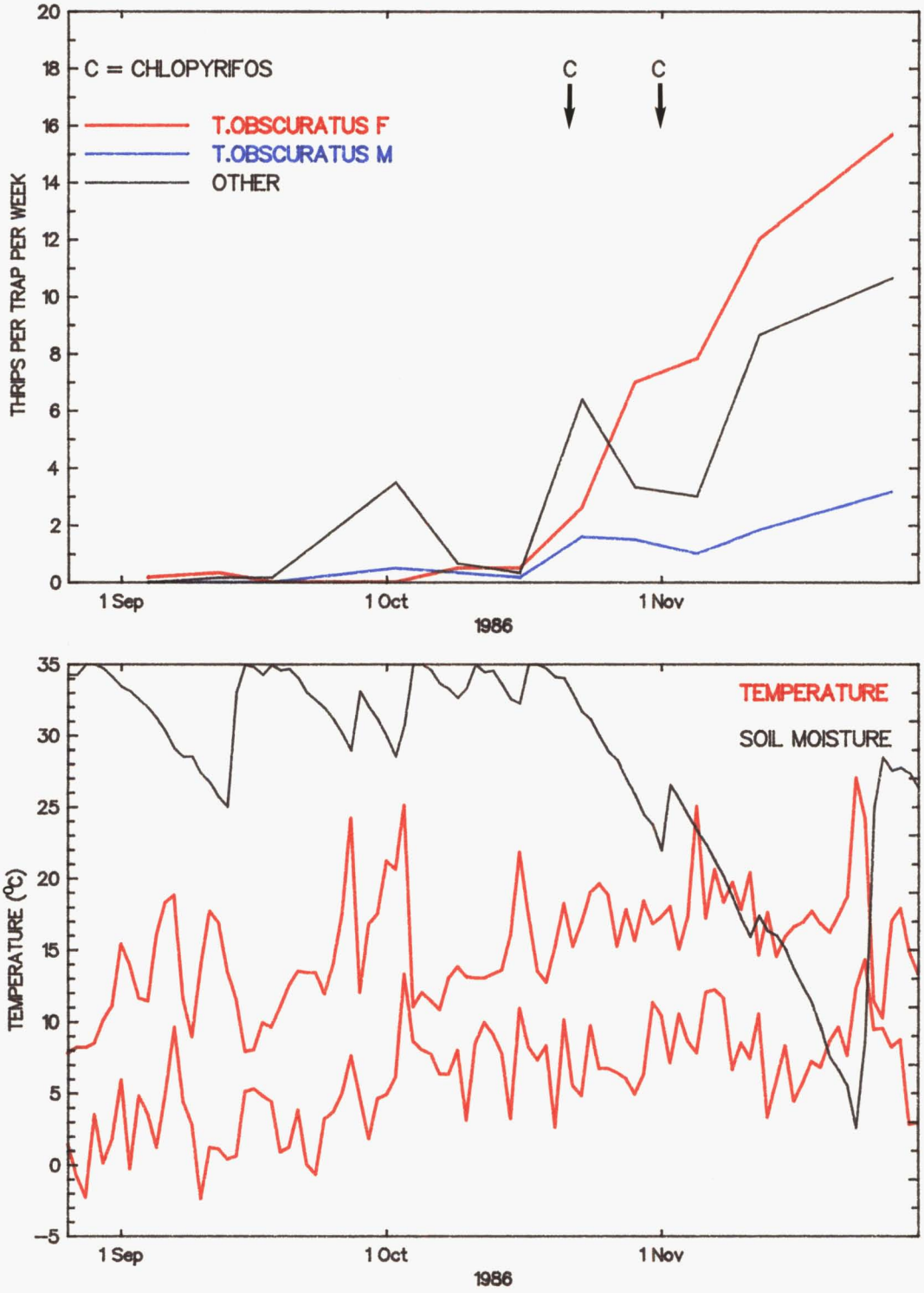


FIGURE 6.5: MEAN NUMBER OF ADULT THRIPS CAUGHT IN WATER TRAPS, OUTSIDE ORCHARD BLOCKS, SPRING 1985.

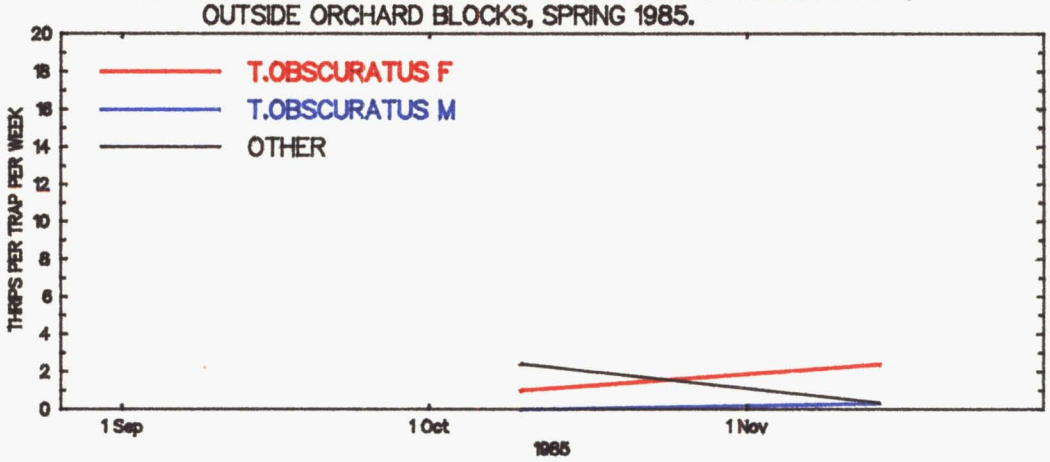


FIGURE 6.6: MEAN NUMBER OF ADULT THRIPS CAUGHT IN WATER TRAPS, OUTSIDE ORCHARD BLOCKS, SPRING 1986.

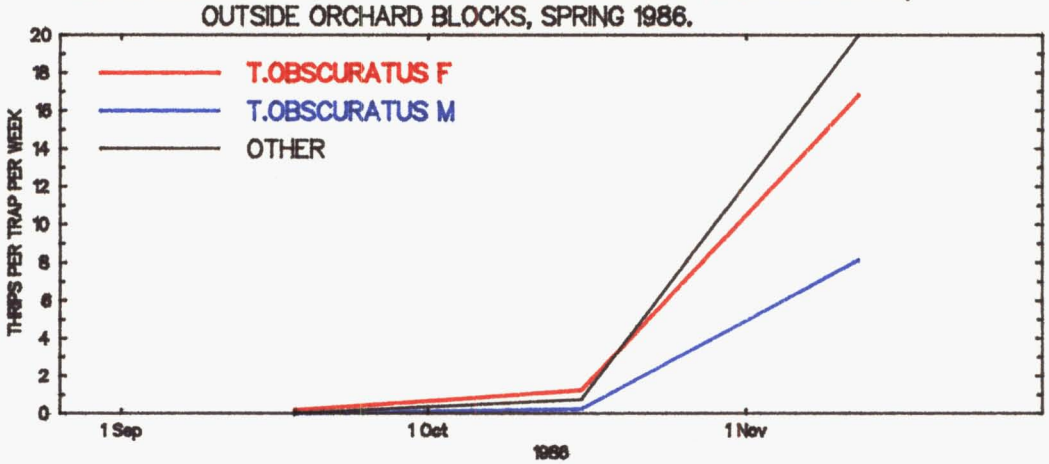


FIGURE 6.7: MEAN NUMBER OF ADULT THRIPS CAUGHT IN WATER TRAPS, BLOCK 1, SUMMER 1985--86, WITH INSECTICIDE APPLICATIONS (↓), MAXIMUM AND MINIMUM TEMPERATURES AND SOIL MOISTURE.

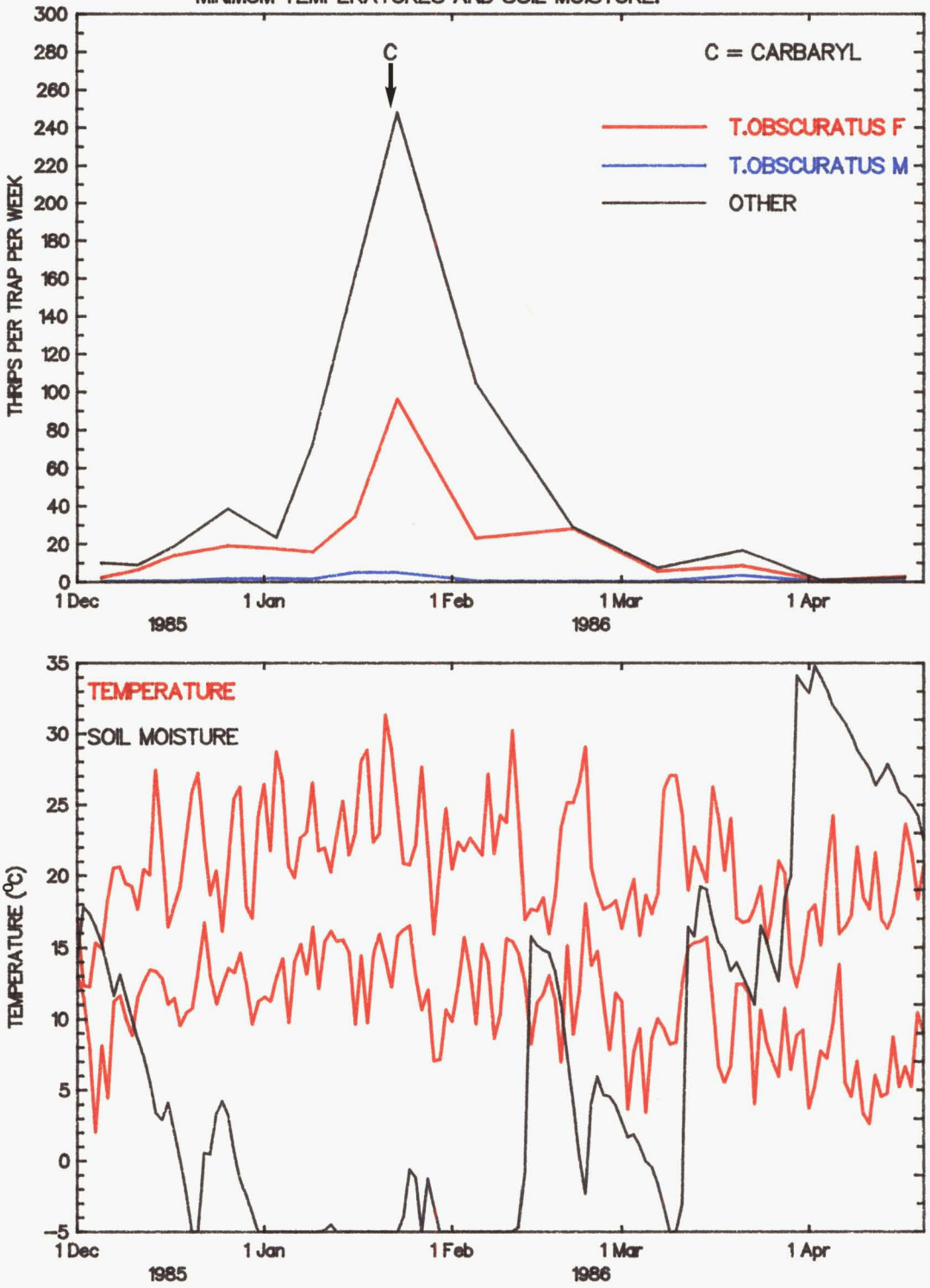
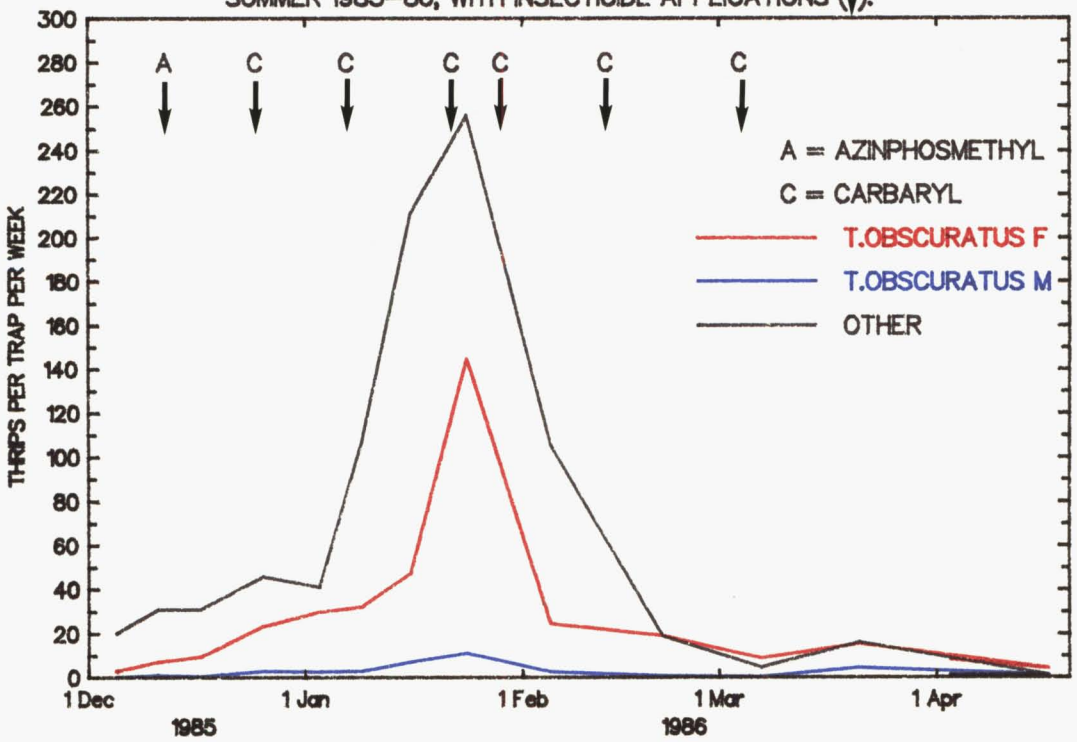


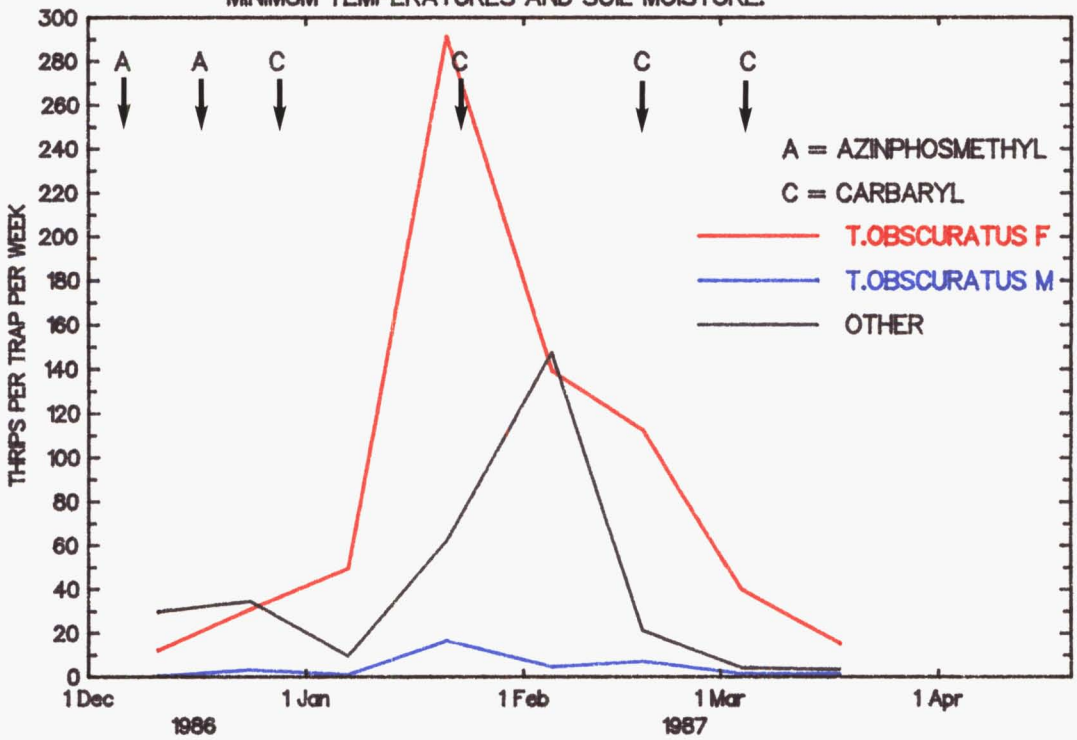
FIGURE 6.8: MEAN NUMBER OF ADULT THRIPS CAUGHT IN WATER TRAPS, BLOCK 2, SUMMER 1985–86, WITH INSECTICIDE APPLICATIONS (↓).



The sharp reduction in thrips numbers in mid to late January (Figures 6.1a, 6.7a, 6.8, 6.9a) could be explained by low soil moisture levels during January. *T. obscuratus* was found to pupate in the soil (see Chapter IV) and humid condtions were necessary to complete pupation (see Chapter III). Evans (1932) found that *Thrips imaginis* pupae did not attain maturity if kept in dry soil. Dry soils may be lethal because they compete with the pupae for moisture (Andrewartha 1934). In the three seasons of thrips sampling in this study, soil moisture levels were close to zero throughout January and sometimes parts of December (Figures 6.1b, 6.7b, 6.9b). In January mean daily temperatures were about 18^{o}C for the three seasons sampled. Egg and larval development was completed within 12 days at 19^{o}C in the laboratory (see Table 3.4). Therefore a period of about 12 days of zero soil moisture in January would kill pupal stages in all thrips generations. In the field samples zero soil moisture levels prevailed for much longer than 12 days, so that mortality of pupal stages from all generations must have occurred.

The period of lag between the beginning of zero soil moisture conditions and the initial summer reduction of adult thrips inside the orchard was about seven, five and six weeks in the 1984-85, 1985-86 and 1986-87 seasons respectively. In the laboratory it was demonstrated that *T. obscuratus* adults lived for about seven weeks at 20^{o}C (see Table 3.4). Thus the onset of zero soil moisture conditions coincided with reduction of thrips adult populations five to seven weeks later. Discrepancies in adult lifespan between the

FIGURE 6.9: MEAN NUMBER OF ADULT THRIPS CAUGHT IN WATER TRAPS, BLOCK 2, SUMMER 1986–87, WITH INSECTICIDE APPLICATIONS (↓), MAXIMUM AND MINIMUM TEMPERATURES AND SOIL MOISTURE.



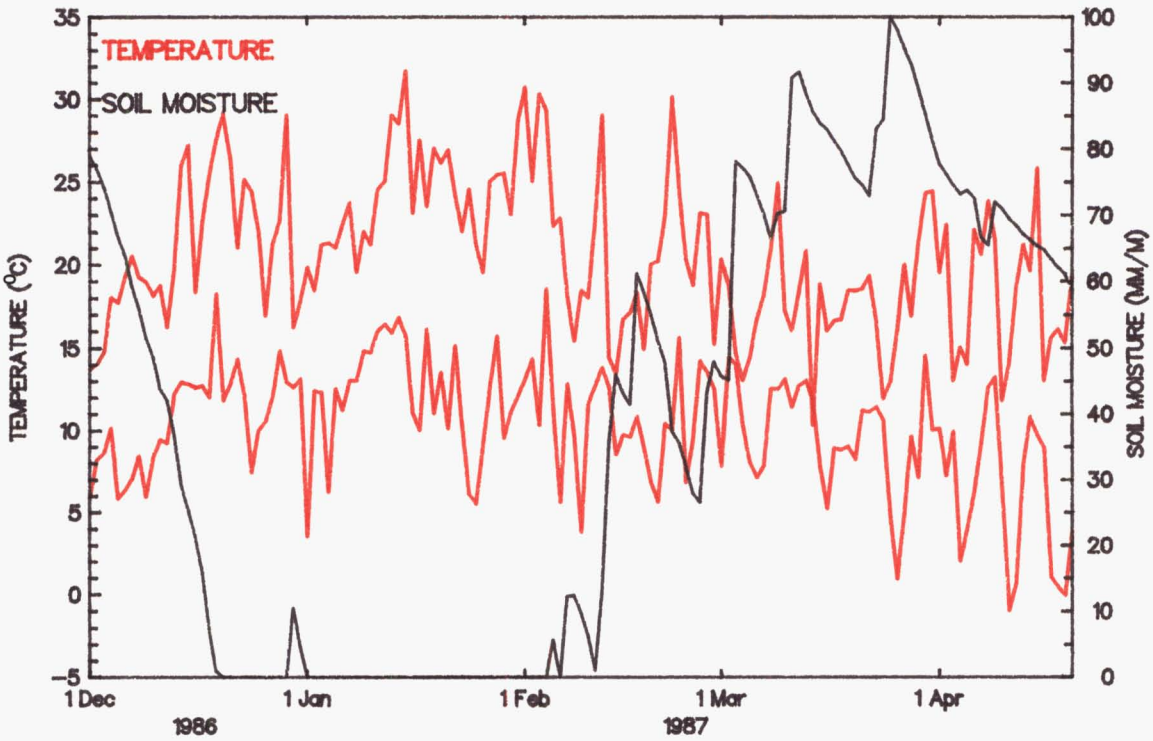


FIGURE 6.10: MEAN NUMBER OF ADULT THRIPS CAUGHT IN WATER TRAPS, OUTSIDE ORCHARD BLOCKS, SUMMER 1985–86.

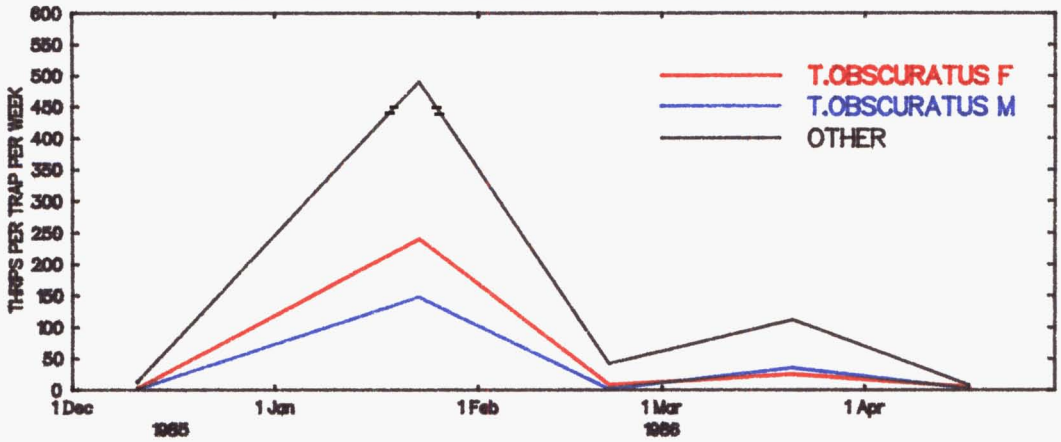


FIGURE 6.11: MEAN NUMBER OF ADULT THRIPS CAUGHT IN WATER TRAPS, OUTSIDE ORCHARD BLOCKS, SUMMER 1986–87.

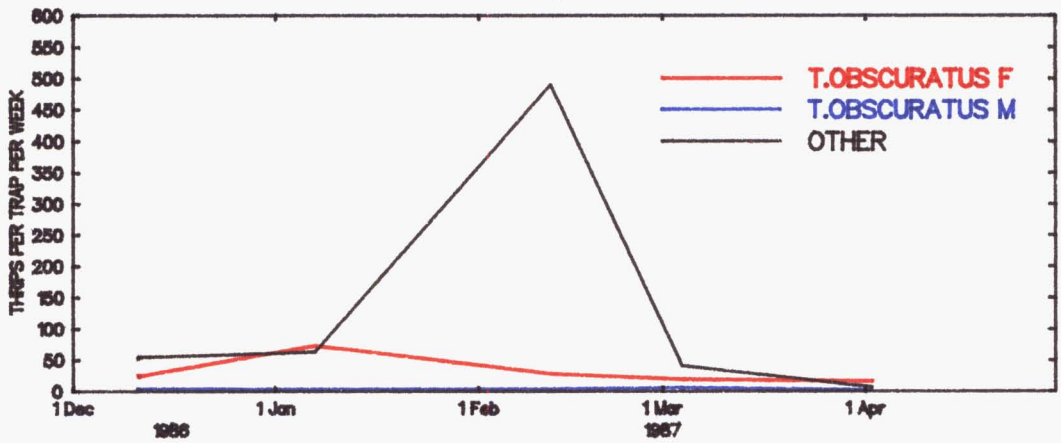


FIGURE 6.12: MEAN NUMBER OF ADULT THRIPS CAUGHT IN WATER TRAPS, BLOCK 1, WINTER 1985, WITH MAXIMUM AND MINIMUM TEMPERATURES AND SOIL MOISTURE.

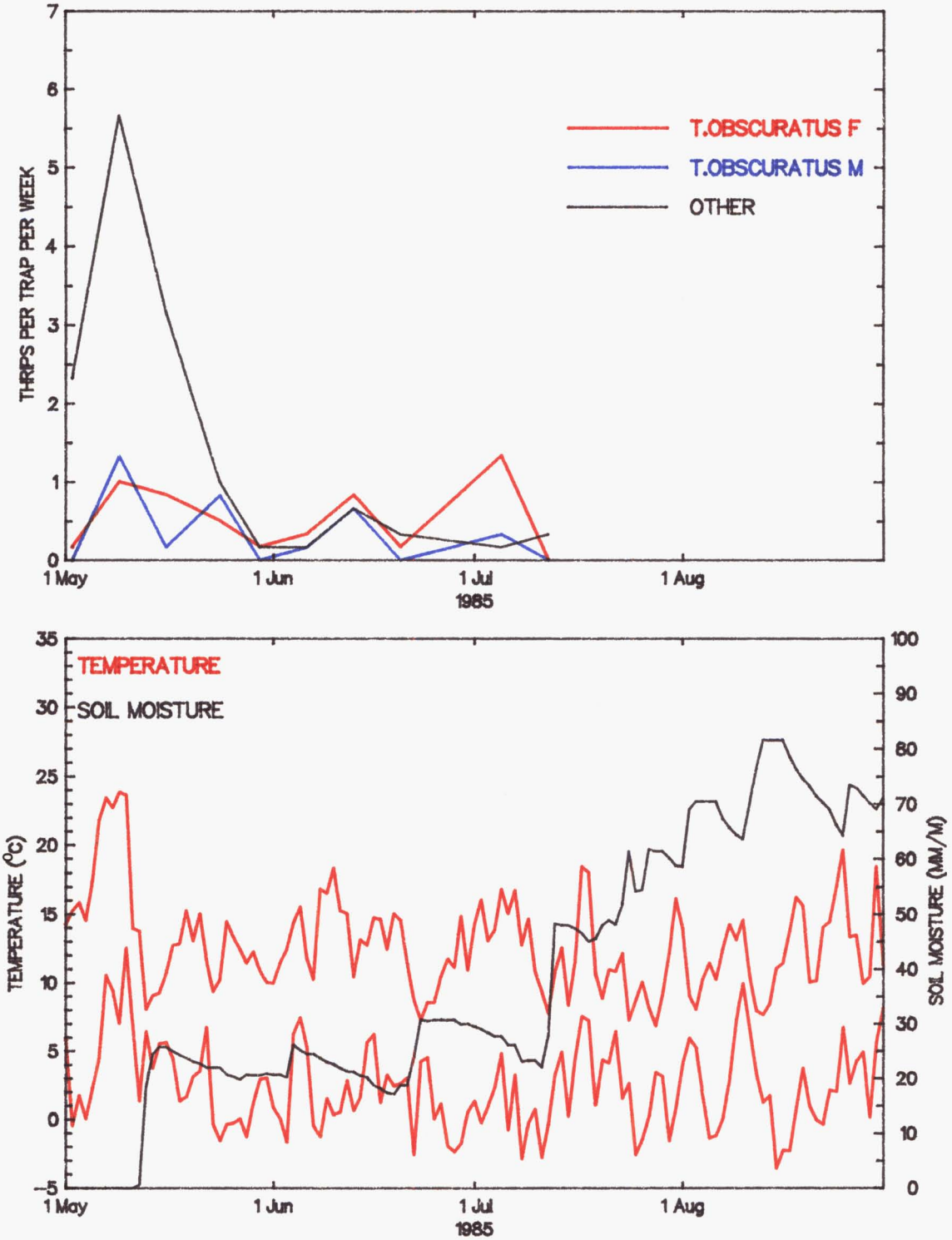


FIGURE 6.13: MEAN NUMBER OF ADULT THRIPS CAUGHT IN WATER TRAPS, BLOCK 2, WINTER 1986, WITH MAXIMUM AND MINIMUM TEMPERATURES AND SOIL MOISTURE.

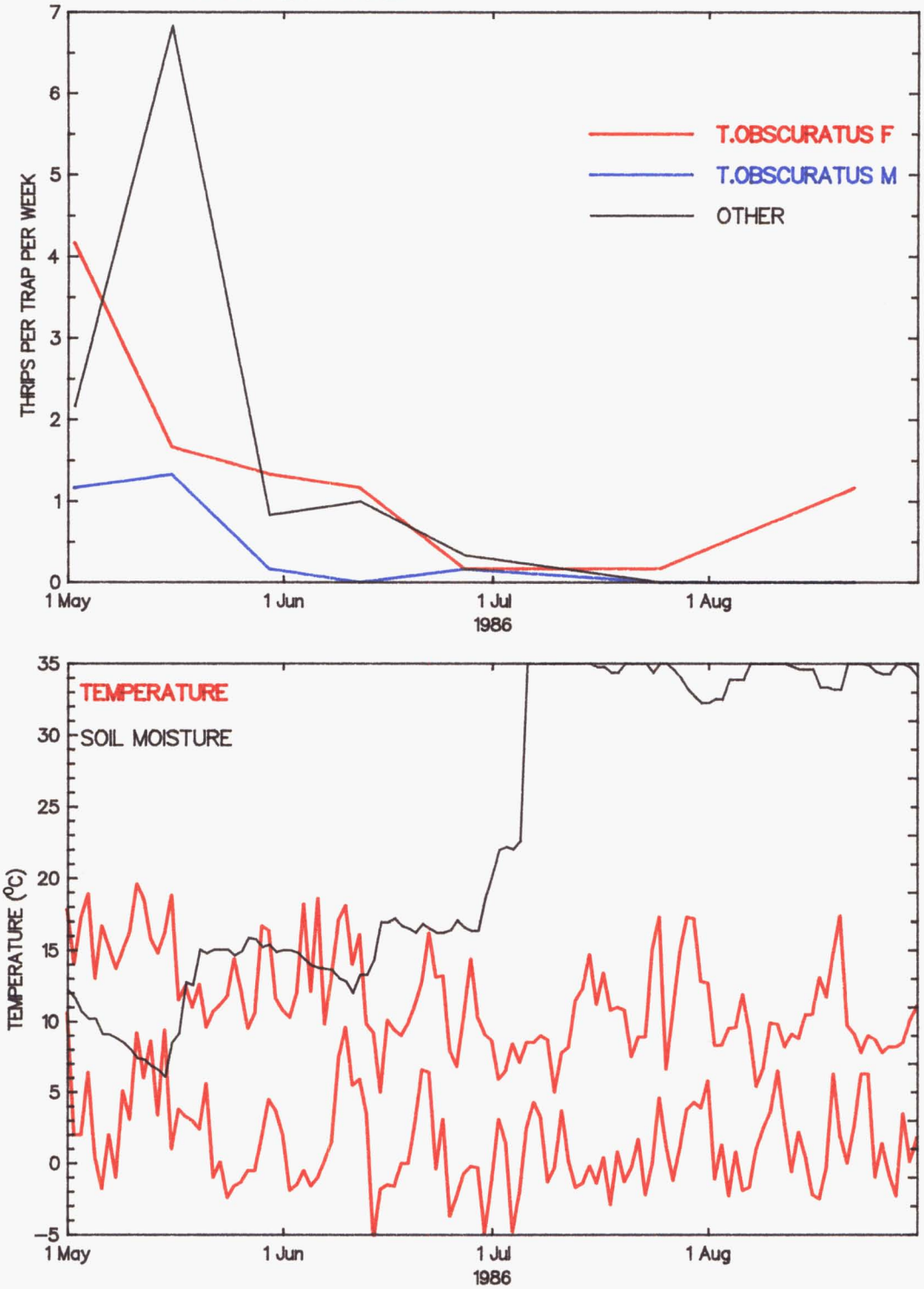
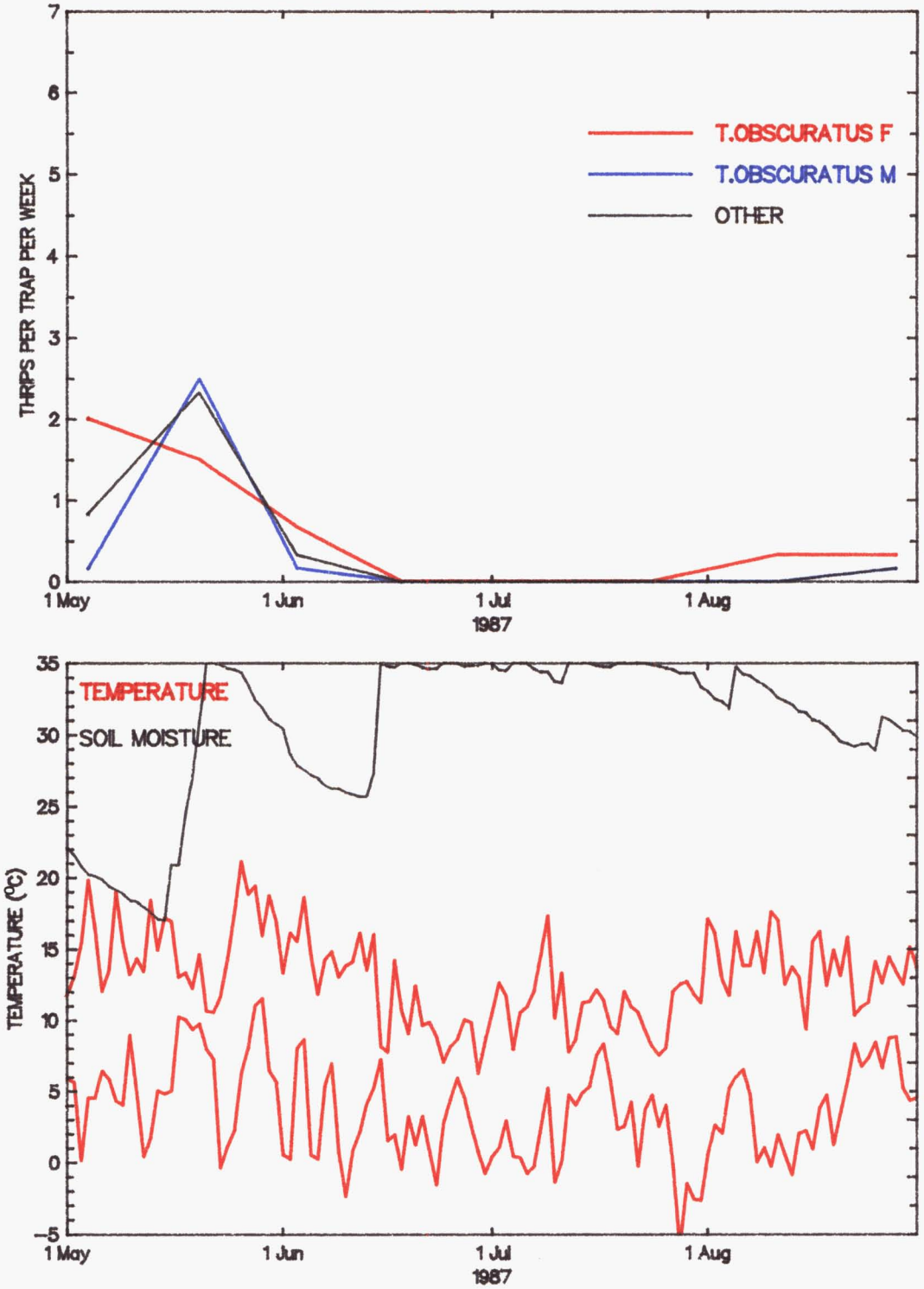


FIGURE 6.14: MEAN NUMBER OF ADULT THRIPS CAUGHT IN WATER TRAPS, BLOCK 2, WINTER 1987, WITH MAXIMUM AND MINIMUM TEMPERATURES AND SOIL MOISTURE.



laboratory and the field may be a result of sampling inaccuracies, differences in develpment rate with different temperature regimes, or differences in adult survival in the laboratory compared to field conditions. The fact that some thrips were still found flying within the orchard after prolonged periods of zero soil moisture may be attributed to localised areas of high soil moisture.

Low soil moisture was considered to be the principal factor responsible for the sudden drop of *Thrips imaginis* numbers in spring and the maintenance of the population at a low level throughout summer in Australia (Andrewartha and Steele 1934, Evans 1934).

From February onwards the number of flowering host species of *T. obscuratus* declined (Figure 6.16), so that even if soil moisture levels increased in late February and March when temperatures were suitable for development and flight, thrips populations remained low (Figures 6.7, 6.9). If soil moisture conditions were suitable for thrips pupation throughout January, a decline in thrips numbers would be expected in late February or early March due to the reduction of breeding host plants. Apart from the number of floral breeding hosts available, soil moisture and temperature conditions were similar in autumn (March, April) and spring (October, November). Thrips numbers increased in spring with the availability of many hosts but declined in autumn when few hosts were available.

T. obscuratus was found to be parasitised by a nematode that sterilised female thrips (see Chapter III). Strong circumstantial evidence indicated that the nematode was *Howardula aptini* (see Chapter IV). Peak parasitism rates of between 60 to 70 percent are known to occur in summer in thrips species infested with *Howardula aptini* overseas (Sharga 1932, Nickle and Wood 1964, Reddy *et al.* 1982). It is possible that this nematode had some influence on the seasonal abundance of *T. obscuratus*, although this was not investigated as parasitism rates were not established.

FIGURE 6.15: MEAN NUMBER OF ADULT THRIPS CAUGHT IN WATER TRAPS, OUTSIDE ORCHARD BLOCKS, WINTER 1987.

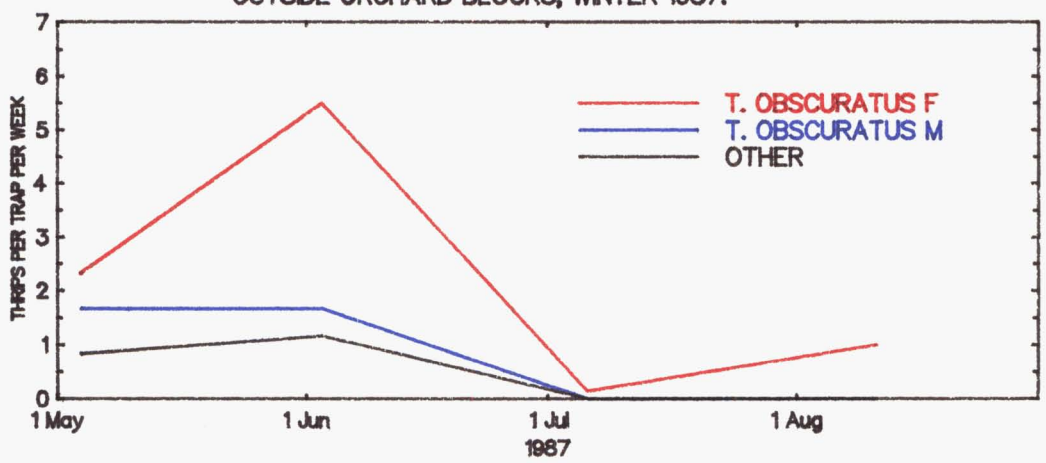
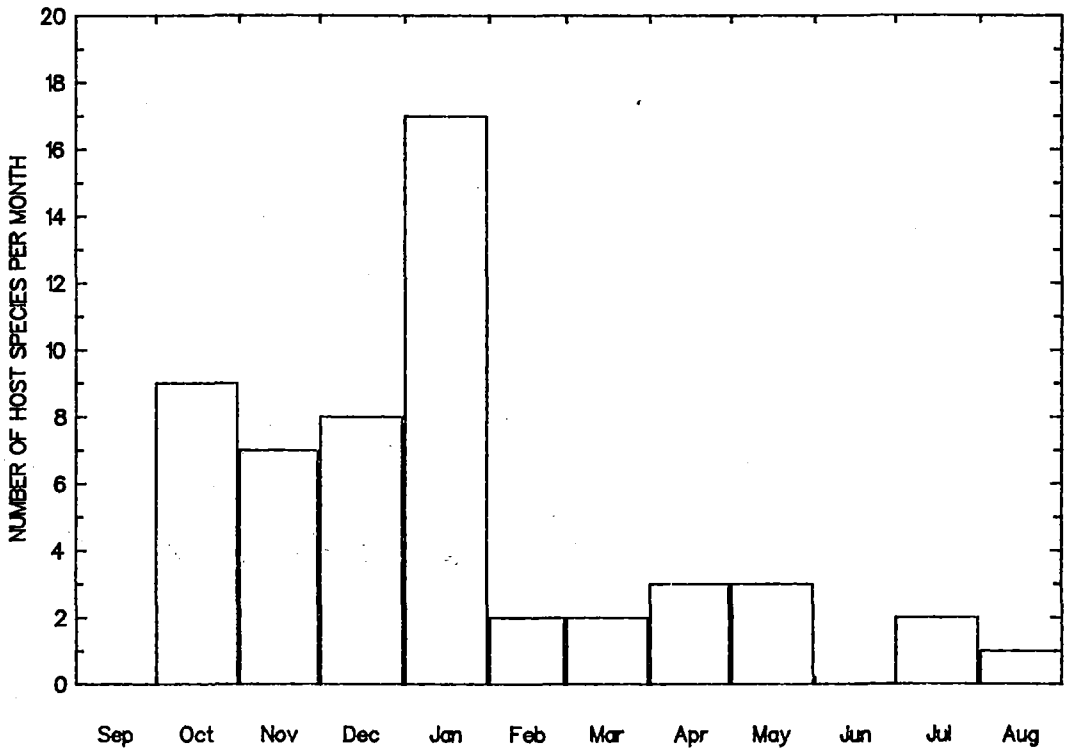


FIGURE 6.16: MONTHLY OCCURENCE OF KNOWN FLORAL HOSTS FOR N.Z. FLOWER THRIPS LARVAE IN CANTERBURY.



There were insufficient data to compare the relative numbers of *T. obscuratus* between seasons. In Australia *Thrips imaginis* outbreaks in spring were shown to follow seasons in which the autumn and winter rainfall were above normal (Evans 1932). Presumably this led to high soil moisture levels in spring so that pupal mortality was low. In the three seasons examined in Canterbury, the soil moisture levels during autumn and winter were high and therefore not likely to limit thrips development. Low temperatures throughout winter may restrict population buildup and in some seasons cause mortality of thrips.

3.3 ABUNDANCE OUTSIDE ORCHARD BLOCKS

Comparison of thrips caught in water traps inside and outside orchard blocks were of limited value because outside samples were taken less frequently and peak periods of thrips flight may have been missed. In spring, numbers of *T. obscuratus* adults trapped inside and outside orchard blocks were similar (Figures 6.2a, cf. Figures 6.5, 6.6). During spring, stonefruit flowers supply feeding and breeding sites for *T. obscuratus* (see Chapter IV) so that the orchard becomes a centre of thrips activity. Outside traps may have caught thrips flying from other hosts.

During the 1985-86 summer more *T. obscuratus* adults were trapped outside the orchard than inside (Figure 6.7a cf. Figure 6.10), but in the 1986-87 summer reverse was observed (Figure 6.9a cf. Figure 6.11). The peak thrips flight in the 1986-87 summer appeared to have been missed by samples outside the orchard although on equivalent sample dates throughout January numbers of *T. obscuratus* adults were lower outside. During summer most hosts of *T. obscuratus* are found outside the orchard, but from December to April thrips were found in large numbers on maturing fruit. It is likely that these adults came from host plants outside the orchard (see Chapter V).

Cruickshank (1987) sampled thrips with water traps placed within the orchard border of a newly-established Canterbury stonefruit orchard, but the overall flight patterns of *T. obscuratus* were strongly influenced by flowering hosts close to some traps.

Consistently higher thrips numbers outside the orchard (Figure 6.14) than inside (Figure 6.15) in the winter of 1987 probably reflected the proximity of flowering hosts and the amount of time when the flight take-off temperature was exceeded. The few breeding hosts of *T. obscuratus* present after May include mustard, *Viburnum* sp. and gorse (Table 4.1). Thrips flying from these hosts would be initially caught by water traps outside but may have taken some time to penetrate into the orchard blocks.

Overall the broad pattern of seasonal abundance of *T. obscuratus* was similar inside and outside orchard blocks. It appears that there is little use in distinguishing populations between the two sites as thrips were continually flying into and out of the orchard blocks in search of host plants.

Other thrips species were caught more often outside than inside the orchard during summer, but numbers were similar during winter. This reflected the absence of host plants within the orchard during summer and that these thrips species were not attracted to ripe fruit. Low numbers of other thrips trapped in spring and winter both inside and outside the orchard may indicate a lack of hosts at these times.

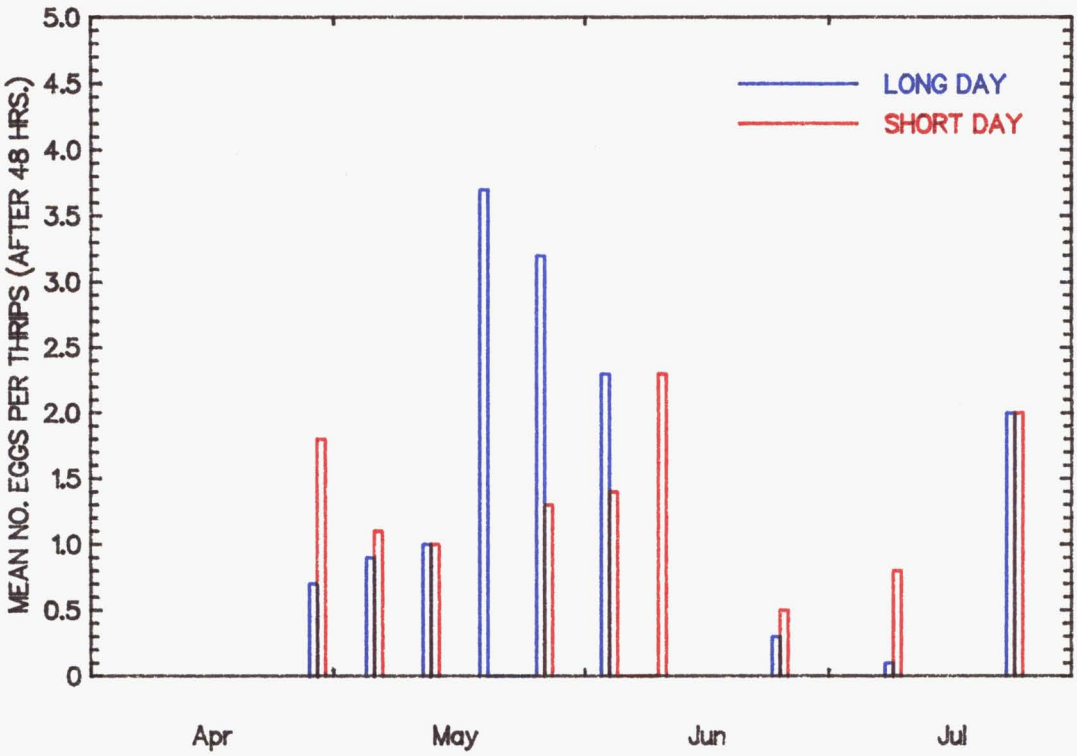
3.4 EFFECT OF INSECTICIDES AND GROUND COVER

Two adjacent stonefruit blocks were sampled for thrips in the 1985-86 summer. Block 1 received only one insecticide application between December and March (Figure 6.7a) and the ground cover included a number of host plants preferred by thrips such as dandelion, clover and yarrow. Block 2 received seven insecticide applications for the same period (Figure 6.8) and the ground was bare. Insecticide application rates are detailed in Appendix 5. The insecticide applications or the presence of ground cover had little effect on thrips flights as similar numbers of thrips were found in both blocks. This reinforces the idea that during summer *T. obscuratus* was continually moving into the orchard from outside host plants. Similarly, insecticides applied to stonefruit blocks in other seasons do not appear to have influenced *T. obscuratus* flights over summer (Figures 6.1a, 6.9a).

3.5 OVIPOSITION ACTIVITY

Adult females collected from flowers throughout May, June and July laid eggs within 48 hours both at long daylengths (16L:8D) and at light regimes equivalent to those prevailing in the field on the day they

FIGURE 6.17: OVIPOSITION OF N.Z. FLOWER THRIPS COLLECTED FROM THE FIELD IN WINTER UNDER LONG AND SHORT DAY CONDITIONS IN THE LABORATORY.



were sampled (see Figure 6.17). All female thrips were identified as *T. obscuratus* except for one *T. australis* on 29/4/85 (long day). This rapid egg-laying response in optimum conditions indicated that there was no diapause in *T. obscuratus*. This concurs with observations of active thrips throughout winter in Central Otago (McLaren 1985). Therefore continuous generations may occur throughout the year and the number of generations per year may be determined by temperature and host availability.

3.6 ECONOMIC IMPLICATIONS

Pest management of thrips on stonefruit is particularly important during flowering for nectarines and at harvest for peaches and nectarines (see Chapter II). It has been shown that *T. obscuratus* infested flowers from pink to shuck fall (Chapter IV) and fruit during the 3 weeks before harvest (Chapter V). The flowering and harvest dates for selected stonefruit varieties in the Lincoln College Horticultural Research Area are listed in Table 6.3 for the 1985-86 and 1986-87 seasons. The time of full bloom for several varieties of nectarines was similar in a given year but changed between seasons. Harvest dates for nectarines and peaches ranged from December to March.

TABLE 6.3: DATES OF FULL BLOOM AND HARVEST FOR SELECTED STONEFRUIT VARIETIES IN THE LINCOLN COLLEGE HORTICULTURAL RESEARCH AREA.

	Variety	FULL BLOOM		HARVEST	
		1985-86	1986-87	1985-86	1986-87
	Nectarines				
	May Grand	6/9	23/9	20/1	16-19/1
*	Firebrite	12/9		31/1	5/2
*	Sunglo	> 12/9		21/2	
*	Redgold	12/9	> 23/9	15/2	16/2
*	Fantasia	12/9	23/9	20-26/2	27/2-9/3
*	Royal Giant	12/9	23/9	14/3	16/3
*	Fairlane	12/9		18/3 -->	
	Peaches				
	Springcrest			30/12-3/1	5-7/1
*	Redhaven			28/1	29/1-2/2
*	Flamecrest			10/2	2/3
*	Fayette			13/3	10/3
	Fairtime			27/3	

* Export varieties

There is little chance of selecting nectarine varieties to minimise thrips infestation at flowering. Firstly, most nectarine varieties flower at much the same time and secondly there are few periods, apart from mid winter, when temperatures fall below the flight take-off threshold and stop thrips flights into the orchard. Later flowering dates are often preferred to reduce the risk of frost damamge (Irving 1986) but this would increase the risk of infestation by thrips.

In three seasons' sampling of thrips flights, *T. obscuratus* numbers declined in mid to late January and remained at medium to low levels throughout late summer and autumn. Ripe peaches sampled in December and January had high numbers of thrips compared to peaches sampled in March and April (see Chapter V). It is thus possible to select peach and nectarine varieties to reduce thrips infestation at harvest. Any stonefruit variety with a harvest date after early February would have lower thrips infestation than earlier varieties because thrips numbers are lower in the orchard. Many of the preferred nectarines in Canterbury, including the predominant export variety 'Fantasia', ripen after early February and are therefore exposed to lower thrips numbers. On the other hand the harvest dates of preferred peach varieties occur earlier, during periods when thrips are more common. The dominant export peach 'Redhaven'

matured at the time of peak thrips flights and was infested with high numbers of thrips at maturity (see Chapter V).

The high numbers of thrips on ripe stonefruit during December and January may necessitate the relegation of fruit varieties ripening at this time to the local market. High levels of thrips on early-season export fruit may jeopardise the acceptance of later season fruit when thrips numbers are lower and control is not as difficult. This is especially important as many of the new stonefruit plantings in Canterbury are aimed at the late season Australian market (Hughes 1985).

The seasonal fluctuations of *T. obscuratus* described in this chapter relate specifically to the conditions experienced during the three seasons of thrips sampling in Canterbury. In other seasons and other areas of New Zealand, seasonal fluctuations in thrips numbers may be different depending on soil moisture, temperature and the availability of host plants at different times of the year. Peak numbers of *T. obscuratus* found in Central Otago by McLaren (1981) and Nelson by Martin (1983) in November may have reflected conditions peculiar to those areas.

4 SUMMARY

Flying thrips were sampled inside and outside stonefruit blocks from September 1984 to August 1987.

Several species including *T. obscuratus, Thrips tabaci, Limothrips cerealium* and *Haplothrips niger* were common. Other species that were consistantly trapped included *Thrips australis, Chirothrips manicatus* and *Ceratothrips frici.*

A broad pattern of the seasonal abundance of *T. obscuratus* was apparent from water trap samples. Thrips numbers were lowest in winter probably as a result of low temperatures and a scarcity of host plants. Thrips numbers were low in spring but increased gradually during summer as temperatures rose and host plants became more common. Numbers peaked in midsummer but declined suddenly in mid to late January. This sudden decrease of thrips numbers coincided with low soil moisture levels. Numbers remained moderate to low throughout late summer and autumn as temperatures decreased and host plants became scarce. This seasonal pattern was reflected by the total number of other thrips species.

Comparison of trap catches outside and inside stonefruit blocks were of limited value because outside samples were taken less frequently. In general, numbers of *T. obscuratus* trapped outside orchard blocks were similar to those trapped inside.

Numbers of *T. obscuratus* were similar in a stonefruit block receiving few insecticide applications and with ground cover including thrips host plants compared to a stonefruit block receiving a number of insecticide applications and no ground cover. This indicates that the source of flying thrips was probably outside the orchard.

Adult *T. obscuratus* females collected from flowers throughout winter laid eggs within 48 hours in the laboratory in short day conditions. This indicated that there was no reproductive diapause.

It is unlikely that nectarine varieties can be selected to minimise thrips infestation at flowering. However peach and nectarine varieties that mature after January are likely to be less infested with thrips than varieties maturing earlier. Therefore selection of later fruiting varieties in Canterbury would improve thrips control.

CHAPTER VII

HOST SELECTION BY THE NEW ZEALAND FLOWER THRIPS

1 INTRODUCTION

Host selection in phytophagous insects consists of a sequence of behavioural responses to an array of stimuli including visual, mechanical, gustatory and olfactory characteristics associated with host and non-host plants (Visser 1986). These may be attractive or repellent. Faegri and van der Pijl (1979) defined primary attractants as those relating to the physiological demands of the visiting insect (e.g., pollen and nectar) and secondary attractants (e.g., odour and colour) which advertise the presence of the primary attractants. Both primary and secondary attractants are thought to guide insects to plants, but because all plants are relatively similar in nutritional value secondary attractants are usually considered the controlling factors (Harborne 1982). A wide range of secondary chemical compounds not directly related to basic plant metabolism have also been implicated as insect feeding stimulants (Harborne 1982).

Behavioural responses of some insects to host stimuli are summarised by Staedler (1977), Kogan (1977), Prokopy and Owens (1983), Kevan (1983) and Visser (1986), but the interaction and importance of the various stimuli for most insects is still an area of speculation.

Prokopy and Owens (1983) put forward a few tentative conclusions on visual stimuli in relation to insect host plant selection: a distant plant on the horizon is detected by an insect primarily on the basis of a gross silhouette against a brighter, more uniformly lit sky. It is only as the insect approaches to within a few metres of a plant that spectral quality (particularly hue and intensity) becomes the predominant cue eliciting detection and alightment. Detailed dimensional or pattern characteristics of plants are used by at least a few species for host detection, but are probably not discernible except at very close range (less than a metre). Background composition (soil, vegetation, sky) can play a major role in host plant detection but is poorly understood.

The role of plant odours in host selection has been traced from the orientation of phytophagous insects toward particular plants over long distances where odour concentration is minute to the ultimate recognition of host plants for feeding and oviposition where the odour concentration is dense (Visser 1986). A large number of volatile compounds leave the plant surface, so that odours may be complex blends with synergistic effects among their components (Visser 1986). Both general and specific odour components have been recognised as attracting insects (Visser 1986).

Colour and odour are considered the most important secondary attractants in relation to flower visiting-insects (Faegri and van der Pijl 1979). Olfactory stimuli induce the visually directed search for flowers (Pellmyr and Thien 1986). Olfaction may be more important, as in the few experimentally studied

cases fragrance alone could direct pollinators to flowers while colour alone could not (Pellmyr and Thien 1986).

An understanding of the factors involved in the attraction of insects, including thrips, to their host plants may have several applications. Traps are frequently used to catch insects for ecological studies or pest monitoring. Appropriately coloured or scented traps discriminately catch different species so that sorting of trap catches is minimised (Lewis 1973, Kirk 1984c). Strong attractants may be used to draw pests away from susceptible plants and repellents to deter infestation. Plant breeders may develop cultivars with scents or colours less attractive to insects to reduce pest infestation (Kirk 1985b).

For thrips, experiments designed to elucidate the mechanisms involved in host selection have been largely restricted to simple field bioassays. Thrips inhabiting different types of host plant have been found to exhibit differential behaviour in response to various colours. The colour preferences of some flower thrips were the colours of their favourite host flower (Czenz 1988), and polyphagous flower thrips show a particular preference for white without ultraviolet (Walker 1974, Kirk 1984b, c). Some floral scents, particularly aldehydes, are attractive to some thrips species (Howlett 1914, Morgan and Crumb 1928, Kirk 1985b). Ethyl nicotinate has proved to be a potent attractant for the New Zealand flower thrips (Penman *et al.* 1982).

T. obscuratus infests many flower species (Chapter IV) as well as ripe stonefruit (Chapter V). Although many thrips species are common inhabitants of flowers, reports of them infesting stonefruit are scarce (e.g., La Rue *et al.* 1972, Pollini and Giunchi 1979) and the factors involved in host selection of stonefruit by thrips has not been investigated. La Rue *et al.* (1972) speculated that *Frankliniella occidentalis* was attracted to nectarine fruit by either colour changes in the fruit or the characteristic aromas which became apparent shortly before picking.

The aim of the work in this chapter was to examine factors involved in host selection by *T. obscuratus* among flowers and fruit. This was achieved with field bioassays measuring the response of *T. obscuratus* to several colours and to known thrips attractants during spring and summer. The application of this knowledge is discussed in relation to pest management of thrips in stonefruit.

2 MATERIALS AND METHODS

2.1 COLOUR

Plastic two litre containers (170 x 170 x 85 mm) (Probit Industries Ltd. Auckland) were used as water traps. They were painted in six colours: white (White, Superseal, Dulux N.Z. Ltd), yellow (Canary Yellow, Super Enamel, Dulux N.Z. Ltd), green (Larch Green, Super Enamel, Dulux N.Z. Ltd), blue (Zenith Blue, Super Enamel, Dulux N.Z. Ltd), black (Black, Super Enamel, Dulux N.Z. Ltd) and red (Mail Red, Brilliant Glass Enamel, British Paints). The spectral reflectance of each colour was measured as a percentage of the reflectance from a white barium sulphate (Eastman White) standard in a Zeiss PMQ3

spectrophotometer between 300 and 800 nanometers (for yellow 370-770 nm). Five traps for each treatment were positioned on the ground in a 5 x 5 m grid with a randomised block design in a field comprising several species of grasses, white clover, and several weed species surrounded by poplars in the Lincoln College Horticultural Research Area (see Appendix 5).

Each trap contained about one litre of water and a few drops of formaldehyde to prevent fungal and algal growth, and detergent to facilitate thrips sinking in the water. The spring trial conducted at the time of stonefruit flowering commenced on 23 October and traps remained in position for 168 hours. A second identical trial was conducted in summer at the time of peak thrips flight. Trapping commenced on 16 January for 96 hours.

2.2 SCENT

White painted plastic two litre containers as above were used as water traps. A small vial (38 mm long x 15 mm dia.) was hung over the mouth of each trap with wire. Each vial contained about 2.5 mls of either *p*-anisaldehyde, benzaldehyde, ethyl nicotinate, distilled water or apple/peach juice (70/30%) ('Fresh-Up' apple/peach juice. The N.Z. Apple and Pear Marketing Board). A cotton wool dental roll was placed inside the vial to act as a wick. Traps were filled and placed as in Section 2.1. The spring trial conducted during stonefruit flowering, commenced on 16 October and traps remained in position for 96 hours. A second trial was conducted in summer just after peak thrips flight with a further treatment. A single unsprayed peach (var. unknown) was hung over the mouth of the traps with wire. Traps were placed in a 6 x 5 m grid in a randomised block design. Trapping commenced on 10 February for 24 hours. Vials were examined during both experiments to ensure that their contents did not dry out.

For all colour and scent trials, all adult thrips were removed at the completion of each sampling period, mounted on slides beneath coverslips with polyvinyl alcohol (P.V.A.) and left to clear for at least 24 hours (Walker and Crosby 1979). All terebrantian thrips were identified according to Mound and Walker (1982).

For each trial ANOVA and Duncan's new multiple-range test (Steel and Torrie 1960) were used to test significant differences between treatments for the number of *T. obscuratus* adults caught for each trial. Males and females were analysed seperately. Data were transformed (log (x+1)) to reduce the dependence of the variance on the mean.

3 RESULTS

Several species of thrips were caught in the water traps during these experiments. In both spring and summer, thrips species commonly caught included *T. obscuratus*, *Thrips tabaci* and *Limothrips cerealium*. *Ceratothrips frici* was common in the summer only. Other thrips trapped in low numbers included *Chirothrips manicatus*, *Thrips australis*, *Frankliniella occidentalis*, *Anaphothrips obscurus*, *Thrips vulgatissimus*, *Aeolothrips fasciatus* and a few other unidentified Terebrantia and Tubilifera. Thrips

numbers and species diversity were higher in summer than in spring. Only trap catches for *T. obscuratus* males and females were analysed. Trap catches for other thrips species are listed in Appendix 16.

The spectral reflectance curves for water trap colours are given in Figure 7.1. All colours including white had low levels of ultra-violet (U.V.) reflectance.

Insufficient numbers of *T. obscuratus* adults were trapped in spring to indicate any colour preferences (Appendix 16), and statistical analysis was not undertaken. In summer both male and female thrips showed a strong preference for white. Significantly more thrips were caught in white traps than any other colour except for yellow (females only). White traps caught 2.5 times more adult females than yellow traps, but the difference was not significant. Red traps caught significantly fewer females than yellow and white traps but otherwise all other colours trapped equivalent numbers of *T. obscuratus* males and females (Table 7.1).

Ethyl nicotinate baited traps caught significantly more *T. obscuratus* males and females than all other traps in both spring and summer (Table 7.2). The scent of ethyl nicotinate increased the catch of *T. obscuratus* by a factor of up to 73 in spring and 141 in summer compared to unscented controls. Anisaldehyde baited traps caught significantly more thrips than all other traps except for ethyl nicotinate and benzaldehyde (summer only). Benzaldehyde baited traps caught more thrips than other traps except for those baited with ethyl nicotinate and anisaldehyde, although the difference was not significant in spring. Numbers of thrips caught by traps baited with peach juice and peach fruit (summer only) were not significantly different from the controls.

4 DISCUSSION

4.1 HOST SELECTION: GENERAL

The significance of *T. obscuratus* adults' preference for white and to a lesser extent yellow is apparent when the colour of host plant flowers is considered. About 60% of the breeding host flowers of *T. obscuratus* are white, and another 20% are yellow (Table 4.1). New Zealand endemic plants have an unusually high proportion of white flowers and a relative lack of blue, purple and red hues compared to other floras (Lloyd 1985). As *T. obscuratus* is itself endemic and a generalist flower inhabitor, its preference for white could be a significant factor in floral host finding among endemic plants.

Other studies shown that thrips species in different habitats respond to different colours (Walker 1974, Kirk 1984c, Czenz 1988). Kirk (1984a) found that some flower-associating thrips were caught in larger numbers in traps coloured white (without U.V.), yellow and blue compared to white (with U.V.), green, red or black. Czenz (1988) found that at least one of the colours, yellow, white or blue, were preferred by separate species of flower thrips. The polyphagous flower thrips, *Frankliniella tritici* and *Thrips imaginis*, were both more attracted to white (without U.V.) than any other colour (Walker 1974, Kirk 1984b).

FIGURE 7.1: SPECTRAL REFLECTANCE OF COLOURED WATER TRAPS.

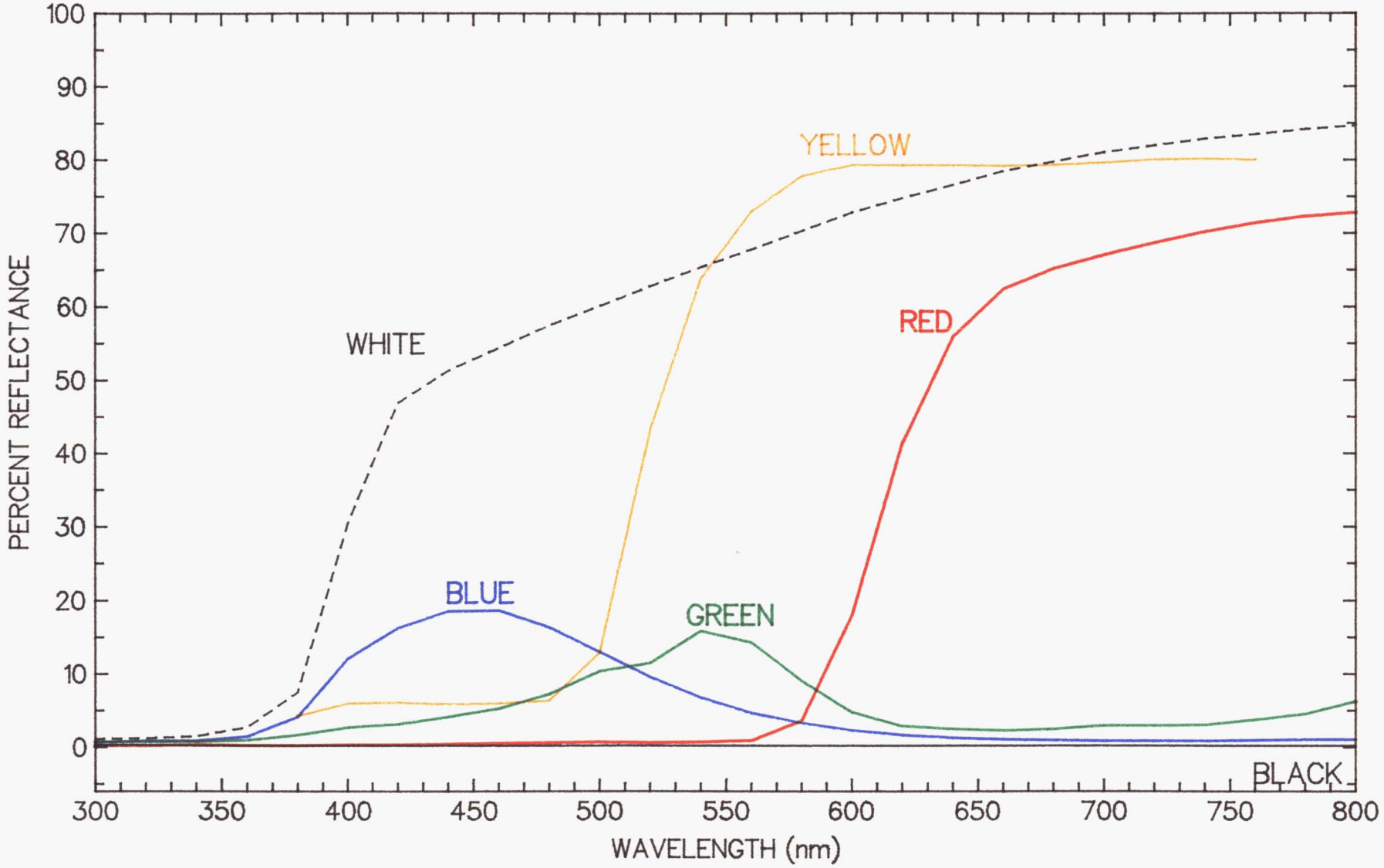


TABLE 7.1: MEAN NUMBER OF NEW ZEALAND FLOWER THRIPS ADULTS CAUGHT IN COLOURED WATER TRAPS IN SUMMER (96 HOURS).

Colour	Female		Male	
White	5.8	A*	5.6	A
Yellow	2.2	AB	1.2	B
Green	0.8	BC	0.2	B
Blue	1.4	BC	0.6	B
Black	1.0	BC	0.4	B
Red	0.2	C	0.2	B

* letter indicates differences at $p < 0.05$ for transformed data (log x+1)

Table 7.2: MEAN NUMBER OF NEW ZEALAND FLOWER THRIPS ADULTS CAUGHT IN BAITED WATER TRAPS, IN SPRING (96 HOURS) AND SUMMER (24 HOURS).

	SPRING				SUMMER			
Attractant	Female		Male		Female		Male	
ethyl nicotinate	59.0	A*	89.0	A	141.2	A	22.4	A
p-anisaldehyde	5.0	B	3.6	B	33.8	B	6.2	B
benzaldehyde	1.8	C	0.8	C	35.0	B	2.0	B
peach juice	0.6	C	0.0	C	1.2	C	0.0	C
peach fruit	-		-		1.8	C	0.0	C
control	0.8	C	0.0	C	1.0	C	0.2	C

* letter indicates differences at $P < 0.05$ for transformed data (log x+1)

The colour preferences of *T. obscuratus* were similar to those of other polyphagous flower inhabiting thrips such as *Frankliniella tritici* and *Thrips imaginis*. More thrips were caught in white (without U.V.) than in any other colour. As with *Frankliniella tritici* (Walker 1974), yellow was the next most attractive colour for *T. obscuratus* and green, blue, red and black caught relatively few thrips. *T. obscuratus* was not attracted to blue as was *Thrips imaginis* (Kirk 1984b). This may reflect the scarcity of blue flowers in the New Zealand endemic flora (Lloyd 1985).

Guldberg and Atsatt (1975) found that approximately 33% of all flowers significantly reflect ultra-violet (U.V.). Yellow and violet flowers had the highest probability of reflecting U.V., while white and green flowers generally reflected U.V. poorly (Guldberg and Atsatt 1975). White flowers examined by Walker (1974) and Kirk (1984b) also reflected little U.V.. As white flowers constitute a large proportion of *T. obscuratus* hosts (see above) *T. obscuratus* is probably not as attracted to white with U.V. compared to white (without U.V.). This is similar to other flower thrips, and should be considered in selection of trap colours for sampling.

Benzaldehyde and anisaldehyde have been found to be attractive to a number of thrips including polyphagous flower-inhabiting species (Howlett 1914, Morgan and Crumb 1928, Kirk 1985b). Benzaldehyde and to a lesser extent anisaldehyde are common components of flowers (Naves and Mazuyer 1947, Borg-Karlson and Groth 1986, Pellmyr *et al.* 1987, Patt *et al.* 1988), including some such as lucerne, elder and peony (Buttery *et al.* 1982, Toulemonde and Richard 1983, Kumar and Motto 1986) which are hosts of *T. obscuratus*. Benzaldehyde is also a common constituent of fruit (MacLeod and de Traconis 1982, MacLeod and Pieris 1982, Idstein *et al.* 1984, Idstein and Schreier 1985) including peach (Sevenants and Jennings 1966, Do *et al.* 1969).

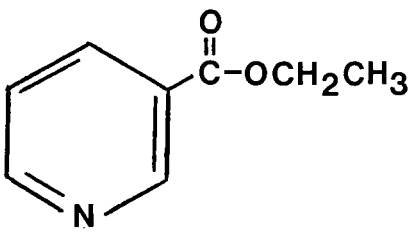
As benzaldehyde and anisaldehyde attract *T. obscuratus* and are present in many plant odours, they are probably constituents of the floral aroma of many *T. obscuratus* hosts. They may be involved in the attraction of *T. obscuratus* either as specific attractants or as components of the total floral bouquet.

Ethyl nicotinate was found to be a potent attractant for *T. obscuratus* by Penman *et al.* (1982), and in the experiments reported in this chapter traps baited with ethyl nicotinate caught significantly more *T. obscuratus* adults than any other scent. Ethyl nicotinate has been found in low concentrations in the fruit of carambola (*Averrhoa carambola* L.) but has not been reported in other foods (Wilson *et al.* 1985) and does not appear to be a constituent of any floral fragrances. Nicotinic acid and its derivatives (methyl, propyl and butyl nicotinate) have also not been reported from the aroma of any flowers. Methyl nicotinate has been found in nuts and coffee (van Straten and de Vrijer 1973 in Wilson *et al.* 1985).

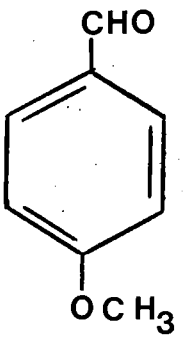
The significance of ethyl nicotinate as an attractant for *T. obscuratus* is unclear. At least two explanations are possible. Firstly, ethyl nicotinate may be found in small but virtually undetectable quantities in the hosts of *T. obscuratus* and play an important role in host selection. As techniques for identifying the volatile components of floral and fruit odours improve, ethyl nicotinate may prove to be more common than previously thought. The second interpretation is that ethyl nicotinate is extremely rare and not normally experienced by *T. obscuratus*, but simply happens to elicit a strong response when detected by olfactory receptors. The molecular structure of ethyl nicotinate is not dissimilar to benzaldehyde and anisaldehyde which are probably involved in the attraction of *T. obscuratus* to flowers and fruit (see Figure 7.2). *T. obscuratus* like other generalist thrips (Kirk 1985b), may respond to a wide range of scents usually associated with flowers.

FIGURE 7.2: STRUCTURAL FORMULAE FOR THRIPS ATTRACTANTS.

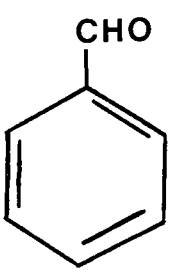
ethyl nicotinate



p-anisaldehyde



benzaldehyde



4.2 HOST SELECTION: STONEFRUIT

T. obscuratus is probably attracted to nectarine and peach flowers, as it is to any other flower, by the interaction of chemical and visual stimuli. Nectarine petals are pink but the white stamens and anthers are clearly visible and could constitute attractive visual stimuli. Flower volatiles such as benzaldehyde and anisaldehyde may also be important in the attraction of thrips to nectarine flowers. The floral odours of nectarines and peaches have not been analysed.

In the field bioassays, ripe peaches and peach juice were no more attractive to *T. obscuratus* than unbaited controls. However, a large number of volatiles are known from the scent of peach fruit which increase in concentration with advancing fruit maturity (Sevenants and Jenning 1966, Do *et al.* 1969). Benzaldehyde was the predominant volatile found by Do *et al.* (1969) in tree-ripe peaches. Traps baited with benzaldehyde were attractive to *T. obscuratus*. The vials of undiluted chemicals in the field bioassays probably produced much higher concentrations of scent than peach fruit and juice, so that the relative attractiveness of peach fruit and juice was minimal. Without knowing the actual vapour concentration distribution around plants it is not easy to relate the concentrations of pure compounds used in experiments to those that occur naturally (Kirk 1984b), so the results of these trials may not have accurately reflected the attractiveness of peach fruit.

The aroma of peach and apricot fruit is a mixture of several compounds (Sevenants and Jennings 1966, Tang and Jennings 1967, Do *et al.* 1969, Spencer *et al.* 1978). Of those belonging to peach fruit aroma ethyl acetate, acetaldehyde, acetic acid, and benzyl alcohol have also been found to be attractive to *T. obscuratus* but not as strongly as anisaldehyde, benzaldehyde or ethyl nicotinate (Teulon unpubl.). Many of these compounds are also constituents of flower aromas (e.g., Buttery *et al.* 1982, Toulemonde and Richard 1983, Kumar and Motto 1986, Borg-Karlson and Groth 1986, Pelmyr *et al.* 1987, Patt *et al.* 1988). This suggests that several chemical compounds may be involved in the attraction of thrips to flowers and fruit.

During ripening the green colour of immature fruit fades with the destruction of chlorophyll. This reveals other colours, especially yellows which were previously masked by green (Jackson 1980). Red colours are the result of anthocyanin synthesis in the fruit skin. The colour changes of the skin of selected peach varieties have been quantified by Bittner and Norris (1968) with spectral reflectance measurements. In field bioassays, *T. obscuratus* females, which were the most common thrips on ripe stonefruit, were most attracted to white and yellow (see Table 7.1) and least attracted to red. Therefore, the development of yellow colours of peach fruit at maturity may attract thrips but this would be counteracted by the extent of development of red.

In other frugivorous insects, host fruit are detected on the basis of shape, intensity of reflectance and size (Prokopy and Owens 1983). The endemic *T. obscuratus* is unlikely to have developed specific host-finding mechanisms for stonefruit, as stonefruit arrived in New Zealand very recently. The mechanisms for attraction of *T. obscuratus* to stonefruit must be closely related to the mechanisms involved in their attraction to flowers. Since stonefruit is never white, odour is presumably significant for fruit selection by thrips. Pellmyr and Thien (1986) indicated that olfaction may be more important than vision for host selection by pollinators.

Two other attributes of ripening stonefruit may also influence the level of thrips infestation. Firstly, during the later stages of fruit maturity there is a considerable increase in the size of cells and a concomitant

thinning of cell walls leading to a softening of the fruit flesh (Zucconi 1986). Sugar accumulates throughout development rising markedly as the fruit swells in the later stages of maturation (Zucconi 1986). The soft flesh, rich in sugar, makes an ideal substrate for thrips feeding and oviposition and probably provides a strong arrestant for thrips which have landed on the fruit.

The combined effect of several stimuli must provide the requirements for thrips infestation of stonefruit, as single attractive stimuli do not bring about thrips infestation of other plants. For example, benzaldehyde is a component of the odour of several fruit occurring in New Zealand including cherry (Nelson and Curl 1939, Spanyar *et al.* 1964), but these fruit are not infested by *T. obscuratus*. Other yellow fruit such as apples (e.g., var. 'Golden Delicious') are also not infested with thrips. Differences in thrips infestation rates between peaches, nectarines and apricots may be due to differences in attractant stimuli such as fruit odour and colour and arrestant properties such as flesh softness and sugar content, as well as the level of humidity of the fruit skin (see Chapter V). The odour of apricot fruit has not been found to contain benzaldehyde (Romani and Jennings 1984) but apricots like peaches are characterised by the presence of several lactones (Sevenants and Jennings 1966, Tang and Jennings 1967, 1968, Do *et al.* 1969). Lactones are considered as important components of the characteristic peach odour (Do *et al.* 1969, Spencer *et al.* 1978). The attractiveness of this group of chemicals to *T. obscuratus* should be examined as they may be important components in the selection of stonefruit by thrips, even though they do not appear to be common constituents of flower aromas.

The results of these experiments indicate that *T. obscuratus* adults have different behavioural responses to certain specific spectra (hues) as well as a number of volatile chemicals. It is likely that this behaviour is involved in the selection of host plants, but the relative importance of each factor at different stages in the process of host selection can only be speculated upon. An understanding of the host selection process of *T. obscuratus* is far from complete. Nevertheless, the information gained from the field bioassays described in this chapter have several applications to the pest management of *T. obscuratus* in stonefruit.

4.3 ECONOMIC CONSIDERATIONS

White (without U.V.) was found to be the most attractive colour to both *T. obscuratus* males and females compared to yellow, green, blue, black and red. As white (without U.V.) traps caught *T. obscuratus* in a higher ratio to other species than did other coloured traps (except for blue and black which caught few thrips) white (without U.V.) traps should be for sampling *T. obscuratus*. In this study white (without U.V.) water traps were used to sample *T. obscuratus* flights successfully over several years (see Chapter VI).

During stonefruit flowering in spring, white water traps caught few *T. obscuratus* adults (see Chapter VI, also Cruickshank 1987) even though thrips were present in flower samples. In the field bioassays described in this chapter traps baited with ethyl nicotinate in spring caught up to 70 times more *T. obscuratus* adults than the controls and 17 times more *T. obscuratus* adults than the next most attractive scent, anisaldehyde. In an insecticide trial investigating the infestation of nectarine flowers by thrips, white water traps baited with ethyl nicotinate were very effective for indicating the presence and pattern of *T. obscuratus* adults (see Chapter VIII). Ethyl nicotinate is therefore a useful attractant for monitoring low thrips populations.

A greater understanding of the scents and colours involved in host selection by thrips could be of use to plant breeders aiming to develop cultivars less liable to thrips attack (Kirk 1985b). Research in this area is handicapped by the lack of positive identifications of floral fragrance compounds (Williams 1983) including those from peach and nectarine flowers. Nectarine flowers with less attractive or actively repellent scents and colours to thrips may be selected to reduce thrips infestation, and the same applies to fruit. Varietal differences for peach odour and flavour have been found and freestone peaches are thought to have a greater aroma intensity than clingstone peaches (Spencer *et al.* 1978). However, it is generally considered that the characteristic odour given off by ripe peaches is also important in terms of flavour (Spencer *et al.* 1978, Jackson 1980) so that selecting stonefruit varieties with odours that are not attractive to thrips may result in fruit that is less acceptable to the consumer.

One aspect of thrips host plant selection that may be easily manipulated for pest management of thrips on stonefruit is fruit colour. *T. obscuratus* females which are the predominant thrips infesting ripe stonefruit (Chapter V), were least attracted to red compared to several other colours, especially white and yellow (Table 7.1). Ripe nectarine and peach fruit colour varies considerably with variety from completely yellow to completely red. In terms of thrips pest management, selection of red fruit may be effective in reducing thrips infestation on fruit. Red fruit are also considered to have most appeal to consumers, and red varieties can be selected to reduce thrips infestation: for example 'Fayette' and 'Golden Queen' peaches are basically yellow whereas 'Early O'Henry' peach is dark red all over. The nectarine varieties 'Early Red One' and 'Red June' have a cherry red colour. Selection of varieties that colour earlier in the maturation process should be advantageous, as infestation of thrips on stonefruit occurs three weeks before harvest (see Chapter V).

Fruit colour can also be manipulated by management practices. Light is one of the main factors responsible for anthocyanin synthesis (Erez and Flore 1986) which produces the red colour of fruit. Therefore tree form, training, shape, vigour, planting density and row orientation are all important considerations that could have a marked effect on fruit exposure to light and hence fruit colour (Erez and Flore 1986).

5 SUMMARY

The role of colour and scent in host selection by *T. obscuratus* was investigated with field experiments with the following findings:

(1) *T. obscuratus* males and females showed a preference for white without U.V., and to a lesser extent yellow, compared to green, blue, black and red.

(2) Traps baited with ethyl nicotinate caught significantly more *T. obscuratus* males and females than traps baited with anisaldehyde, benzaldehyde, peach juice, peach fruit and unbaited traps.

(3) Anisaldehyde baited traps caught significantly more *T. obscuratus* than all other traps except for ethyl nicotinate and benzaldehyde (summer only).

(4) Benzaldehyde baited traps caught more *T. obscuratus* than other traps except for those baited with ethyl nicotinate and anisaldehyde.

(5) The behavioural responses of *T. obscuratus* to colours and scents is discussed in relation to host plant selection in general and stonefruit specifically.

(6) It is likely that behavioural responses to colours and scents are involved in the selection of host plants but the relative importance of each factor at different stages of host selection was not determined.

(7) White without U.V. traps should be used for sampling *T. obscuratus*.

(8) Traps baited with ethyl nicotinate were useful for sampling *T. obscuratus* when population levels were low.

(9) Selection of red nectarine and peach fruit varieties may reduce the level of thrips infestation.

CHAPTER VIII

CHEMICAL CONTROL OF THE NEW ZEALAND FLOWER THRIPS ON STONEFRUIT

The New Zealand flower thrips (*T. obscuratus*) causes economic injury to stonefruit during flowering and at harvest. Past orchard pest control has relied heavily on the use of chemical sprays (Penman 1984, Jackson 1986c), primarily because market tolerance levels for damage and contamination are low. The reliance on chemical controls for thrips has been exacerbated by insufficient knowledge of the biology and ecology of *T. obscuratus*. In the preceding chapters much new information has been gathered on *T. obscuratus*, especially in relation to stonefruit. It suggests that there is potential to develop cultural and biological controls, but it is likely that chemicals will remain the main strategy for preharvest thrips control in the near future. The effectiveness of chemical controls can be enhanced with a thorough understanding of the pest's biology and ecology.

In this chapter the effectiveness of recommended chemical applications for thrips control on stonefruit at flowering and harvest will be examined and alternative strategies of chemical control based on the biological information gathered in this study will be proposed.

1 FLOWERING

1.1 INTRODUCTION

Several species of thrips have been associated with damage to stonefruit worldwide (see Table 2.1). Thrips adults invade the flowers from the pink stage and lay eggs until petal fall. Adults and larvae feed on the succulent tissues of the flower until shuck fall. Feeding damage on the ovaries and small fruit result in irregularly-shaped blocks of russet, sometimes associated with fine scar lines, and in severe cases distortion of the fruit. Nectarines are more susceptible to injury than other stonefruit as they have smooth skin and the calyx sticks tightly to the developing fruit, thereby providing protection for the thrips larvae (Bailey, 1938). The cause of russeting on nectarines in New Zealand was not known (Kemp 1959) until McLaren implicated thrips (Anon. 1979). She found that export packout from russeting was reduced up to 40% (McLaren G., unpubl. data) by controlling thrips. Russet is the most important defect of export nectarines in Canterbury (Brooks 1985).

In the 1986-87 season the recommended spray programme for thrips control at flowering in New Zealand involved insecticide applications at bud movement and petal fall followed by two further sprays at

10-day intervals. Insecticides were not applied when the trees were in bloom to avoid bee poisoning, although experimentation has shown that spraying at this time reduces the level of russeting on nectarines (McLaren G., unpubl. data). McLaren (1986) confirmed that the most severe russeting by thrips occurred between full bloom and petal fall by confining and excluding adult thrips from nectarine flowers and fruit. Overseas it was considered that the critical period of damage occurred when larval feeding concentrated on the ovary between petal fall and shuck fall (Bailey 1938, La Rue *et al.* 1972, Bournier 1983, Cravedi and Molinari 1984). Sampling of unsprayed stonefruit flowers in Canterbury indicated that a significant proportion of the thrips present during flowering were larvae (see Chapter IV). G. McLaren (unpubl. data) recommended a treatment at full bloom for nectarines as soon as an insecticide could be registered for use. An insecticide application at this time should also be effective at reducing larval numbers.

This section describes two field trials investigating the effectiveness of insecticides applied for thrips control at flowering on nectarines. Firstly, a preliminary trial examined the effectiveness of a spray programme excluding insecticide applications while the flower was in bloom. A second field trial examined the effectiveness of two insecticides of minimal hazard to bees (Johansen et al. 1983), phosalone and fluvalinate, applied at full bloom.

1.2 MATERIALS AND METHODS

1.2.1 PRELIMINARY TRIAL

Thrips adults and larvae were sampled from nectarine trees in a mixed stonefruit variety block of the Lincoln College Horticultural Research Area (Block 1, see Appendix 5). Only trees in rows 2-5 were sampled; no more than two trees were of a similar variety. The block was subjected to the current recommended pesticide applications, including insecticides for thrips control at bud movement (lindane 50% WP) and 28 days later at 100% petal fall (azinphosmethyl 50% WP) (see Appendix 5).

Thrips were sampled on seven occasions between pink and shuck fall from ten (four on 5/9/84) randomly selected nectarine trees. Twenty flowers were picked below 2.0 m from each tree and placed in collecting cylinders (see Appendix 3). Flowers selected represented an average stage of development for the nectarine trees in that block. In the laboratory thrips were extracted by heat (see Appendix 3). Thrips adults and larvae were counted. Adults were mounted on slides with polyvinyl alcohol (P.V.A.) under coverslips and left for at least 24 hours to clear (Walker and Crosby 1979). Thrips were identified according to Mound and Walker (1982, 1984).

Fruit was harvested during December, January and February. After picking, a subsample of between 30-40 fruit per variety was assessed for russet. Fruit was categorised as to the amount of russet using the Export Summerfruit Grade Standards 1984-85: 0-clean; 1-acceptable for export; 2-rejected for export; 3-rejected for local market (see Appendix 17).

1.2.2 MAIN TRIAL

A nectarine (var. 'Fantasia') block of 16 rows x 37 trees at the Lincoln Springs Orchard, Canterbury, was used for the trial (see Appendix 18). Trees were about 2 m high and in the second season of fruiting. The block was subjected to current recommended pesticide applications, including insecticides for thrips control at bud movement (lindane 50% WP, 19/8/86), 100% petal fall (chlorpyrifos, 50% WP, 14/10/86) and chlorpyrifos as above (4/11/86) 21 days later (see Appendix 18). In each alternate row, three blocks of five trees were selected and randomly assigned to one of the following treatments to give eight replicates of each:

1. untreated, no additional insecticide application.

2. phosalone (Zolone 30% WP) applied at full bloom (1/10/86) (45 g ai/100 litres).

3. fluvalinate (Mavrik Aquaflow 22.3% FC) (4.46 ml ai/100 litres and Citowett (alkylarylpolygycol ether) 25 ml/100 litres).

Treatments were applied at full bloom (1/10/86) with a motorised back-pack sprayer (Solo, Model 423). Trees were sprayed to runoff (about 1 litre per tree or 700 litres per ha).

Nine samples were taken from pink (22/9/86) until 50% split calyx (5/11/86). Fifteen flowers were picked from one randomly selected tree of each five-tree block for the eight rows. The flowers were placed in an enclosed plastic cylinder and transferred to the laboratory. Thrips were extracted from the flowers by heat (see Appendix 3).

At 100% petal fall (14/10/86) one tree was randomly selected from each five-tree block for each of the eight rows. All branches were hand-beaten over a white plastic dish (320 mm x 280 mm), and thrips were quickly caught by aspirator and killed. Friedman's test (Hettmansperger 1984) was used to test significant differences between treatments for adult counts from beating.

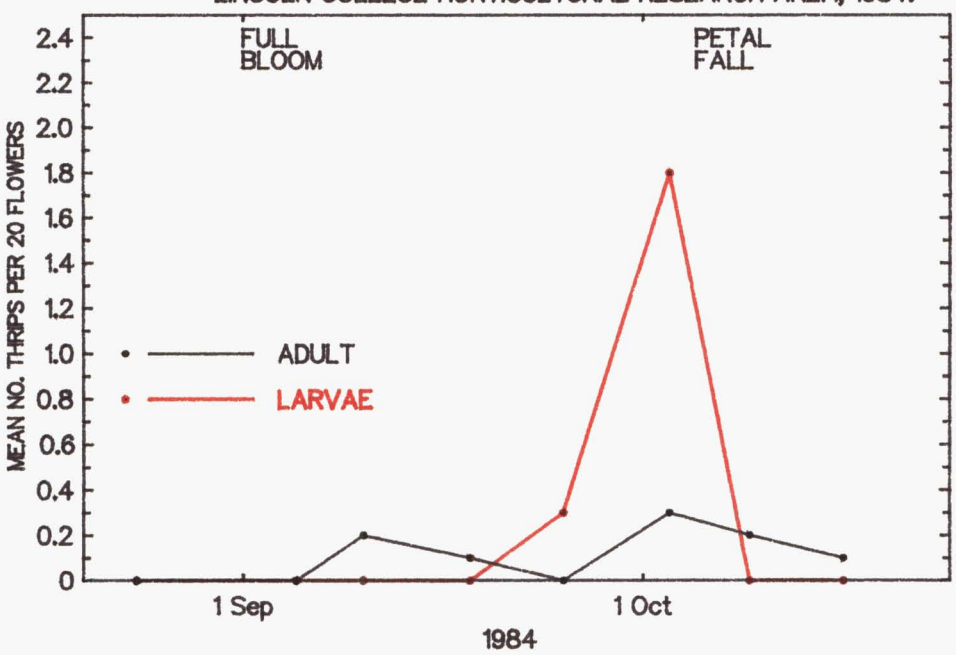
Six water traps placed at regular intervals throughout the block were used to monitor thrips flights. Water traps were white plastic 2 litre containers (170 mm x 170 mm x 85 mm) placed on 1.7 m poles. A small vial (38 mm long x 15 mm dia.), containing about 2.5 mls of the attractant ethyl nicotinate (Penman *et al.* 1982) with a cotton wool dental roll acting as a wick inside the vial, was hung over the mouth of the traps with wire. Baited water traps were placed in the orchard on 25/9/86; each container was supplied with about one litre of water and a few drops of formaldehyde and detergent. Thrips were removed weekly and the fluids renewed. Thrips sampling by baited water traps ceased on 29/10/86. Adult thrips from all sampling methods were identified to species.

At full bloom (2/10/86) ten trees were randomly selected from the entire block and the total number of flowers on each was counted.

All fruit from the three treatments was assessed for russeting between 11-16/2/87 while still on the tree. Fruit was categorised for russet as in Section 1.2.1 but based on the Export Summerfruit Grade

Standards 1986-87 (see Appendix 17). Fruit was harvested on 25/2/87 and 2/3/87. ANOVA and Duncan's new multiple-range test (Steel and Torrie 1960) were used to test significant differences in percent export packout (i.e., grades 0 and 1) between treatments.

FIGURE 8.1: NUMBER OF THRIPS IN SPRAYED NECTARINE FLOWERS, BLOCK 1, LINCOLN COLLEGE HORTICULTURAL RESEARCH AREA, 1984.



1.3 RESULTS AND DISCUSSION

1.3.1 PRELIMINARY TRIAL

The number of adult thrips extracted from nectarine flowers was consistently low over the period of sampling (Figure 8.1). Adult thrips included only *T. obscuratus* (7 females) and *Thrips tabaci* (2 females). Larval numbers were low at all times except around petal fall (Figure 8.1). After the insecticide application at petal fall no larvae were extracted from the flowers.

These results reinforce observations made in Chapter IV concerning thrips infestation of stonefruit flowers. Species composition was similar on sprayed and unsprayed flowers. On unsprayed flowers thrips larvae were found in large numbers at petal fall. They were therefore likely to have inflicted significant feeding damage on the young fruit. In these samples larvae were killed by the petal fall insecticide application. McLaren (1986) found that the most severe russeting by thrips occurred between full bloom and petal fall by confining and excluding adult thrips from nectarine flowers and fruit. These results support the importance of thrips damaging young fruit between full bloom and petal fall but indicate that the presence of larvae is at least as significant as that of the adult. Therefore, an insecticide application of

low toxicity to bees before petal fall to kill thrips larvae and adults should significantly reduce russet on nectarine fruit.

Export pack-out rates for several nectarine varieties are given in Table 8.1. Depending on variety, between 20-60% of the fruit were rejected for export because of russet alone. This represents a significant loss and accentuates the need for chemical applications timed for maximum thrips control. Different levels of russet between varieties could not be considered significant as sample sizes were small.

TABLE 8.1: GRADE STANDARDS (PERCENTAGE) FOR SUBSAMPLED FRUIT OF NECTARINES, BLOCK 1, LINCOLN COLLEGE HORTICULTURAL RESEARCH AREA, 1985.

	GRADE*				NO. OF
VARIETY	0	1	2	3	FRUIT
May Grand	53	13	30	4	30
Early Red III	53	0	44	3	36
Independence	68	12	20	0	40
Summer Grand	28	11	61	0	36
Red Free	33	18	46	3	39
Fantasia	28	19	47	6	36

* assessed for russet only according to the Nectarine and Peach Export Standards 1984/85:
O = clean, 1 = export standard, 2 = rejected for export, 3 = rejected for local market.

1.3.2 MAIN TRIAL

The number of adult thrips extracted from flower samples was consistently low over the period of sampling for all treatments (Table 8.2). Flower numbers per tree averaged 700.4 (S.D., 167.26) at full bloom. Therefore an average of 0.125 thrips per 15 flowers represented about six thrips per tree. Total adult thrips extracted from flowers comprised: *T. obscuratus* 14 females, 3 males; *Thrips tabaci* 5 females, and *Limothrips cerealium* 3 females. Larval numbers on the control trees at 100% petal fall were almost always higher than those on the treated trees although the difference was not significant (Table 8.2). Standard deviations were large (x 2 mean). At 100% petal fall an average of 2.88 larvae per 15 flowers were found on the control trees, or about 134 larvae per tree. On the control trees there were far more larvae at petal fall than adults. The small number of larvae found on the treated trees indicates the effectiveness of the insecticide treatments in reducing oviposition by adults visiting the flowers earlier, and/or killing larvae once they emerge.

TABLE 8.2: MEAN NUMBER OF THRIPS ON NECTARINE DURING FLOWERING, LINCOLN SPRINGS ORCHARD, 1986.

	TREATMENT						
	UNTREATED		FLUVALINATE		PHOSALONE		REMARKS
	adults	larvae	adults	larvae	adults	larvae	
A. Thrips per 15 flowers (flower sample)							
19/08/86							bud movement
							lindane
22/09/86	0.0	0.0	0.0	0.0	0.0	0.0	
29/09/86	0.125	0.0	0.125	0.0	0.0	0.0	
1/10/86							full bloom
							phosalone or
							fluvalinate
3/10/86	0.125	0.0	0.0	0.0	0.125	0.0	
9/10/86	0.0	0.0	0.0	0.0	0.0	0.0	
13/10/86	0.5	2.88	0.125	0.0	0.0	0.625	100% petal fall
14/10/86							chlorpyrifos
16/10/86	0.0	0.625	0.0	0.0	0.0	0.0	
23/10/86	0.25	0.25	0.0	0.0	0.0	0.125	
29/10/86	0.25	0.5	0.125	0.125	0.875	0.5	
4/11/86							chlorpyrifos
5/11/86	0.25	0.0	0.25	0.0	0.0	0.0	
B. Thrips per tree (beat sample)							
14/10/86	4.13		0.5		1.13		100% petal fall

Friedman's test showed that there were differences between treatments ($p < 0.025$) in the number of adults beaten from trees at 100% petal fall. Pairwise multiple comparisons (Hettmansperger 1984) showed significant differences between the control and treatments (see Table 8.3). Mean values are given in Table 8.2. Both phosalone and fluvalinate applied at full bloom were effective in reducing numbers of thrips adults and larvae during flowering when feeding damage to the small fruitlets occurs.

TABLE 8.3: RANKS OF ADULT THRIPS NUMBERS AT 100% PETAL FALL AND PERCENTAGE OF EXPORT GRADE NECTARINES AT HARVEST.

TREATMENT	RANKS OF ADULT NOS.		MEAN PERCENTAGE EXPORT PACKOUT	
Control	22.5	A*	48.2	A#
Fluvalinate	12.5	B	59.3	B
Phosalone	13	B	57.4	B

* Pairwise multiple comparisons.
\# Duncans new multiple-range test.
Differences significant at $p < 0.05$

A similar trial by G. McLaren (pers. comm.) in Central Otago found much lower thrips numbers and higher export packouts (83%) in the controls than in this trial. High thrips numbers in Canterbury may be influenced by the availability of more suitable overwintering hosts (e.g. gorse) or by warm weather before and during bloom. Better control of thrips is obtained if oil is used with lindane at bud movement (McLaren G., pers. comm.). In this trial only one insecticide was applied after petal fall but the effectiveness of sprays after petal fall in terms of increasing export packout is questionable (McLaren 1987).

Several species of thrips were collected in water traps throughout the trapping period (see Appendix 19). After petal fall *T. obscuratus* was the most abundant species although *Thrips tabaci* was also trapped frequently. Of the species caught, these were the only ones thought to be associated with russet in nectarines (G. McLaren, unpubl. data).

McLaren G. (unpubl. data) found *T. obscuratus* to be the predominant species on nectarine trees in Central Otago with several seasons' data from beating samples. The data collected from both flower and beating samples in this study reinforce this. Immature stages of thrips were not identified to species. On unsprayed stonefruit trees adults and larvae were mostly *T. obscuratus* (see Chapter IV).

ANOVA of the percentage export packout figures showed significant differences ($p < 0.0016$) between treatments. Both insecticide applications at full bloom produced significantly higher packout rates than the untreated, but were not different from each other (Table 8.3). Insecticide application at full bloom increased percentage packout by about 10%. Lower russet levels on the treated trees was correlated with the reduction of thrips numbers, both adults and larvae, during flowering.

These results are comparable to those of a similar trial carried out in the 1985-86 season (Teulon, unpubl. data). Phosalone applied at full bloom was included in a spray regime similar to that described for this trial. Export packout of ripe fruit was also increased by 10% in the phosalone treatment. Fluvalinate is now registered for thrips control on stonefruit in New Zealand until shuck fall.

1.4 SUMMARY

T. obscuratus was the dominant species of thrips on sprayed nectarine trees during flowering.

A preliminary trial indicated that the recommended spray programme with insecticide applications at bud movement and 100% petal fall were not fully effective at reducing thrips infestation of nectarine flowers.

In the main trial protection of nectarine flowers from thrips infestation and damage was investigated using the insecticides fluvalinate or phosalone (low toxicity to bees) applied at full bloom as supplements to the current recommended spray programme. Thrips numbers were reduced on trees treated at full bloom. Export packout, based on russet only, was 10% higher for trees treated at full bloom then for those treated only with the recommended spray programme.

2 HARVEST

2.1 INTRODUCTION

The New Zealand flower thrips infests ripening apricots, nectarines and especially peaches (see Chapter V). Females feed and oviposit in the fruit and some larvae hatch before the fruit is picked. Feeding damage is minor unless infestations are severe. The main economic problem is contamination of export fruit by adults, eggs and larvae.

Present preharvest control strategies for thrips on stonefruit rely on applications of the carbamate insecticide, carbaryl (60 g/100 litres), 14 days before, immediately before and at 7-day intervals during harvest (Anon. 1987). Field treatments do not give complete control on peaches and nectarines, so postharvest treatments have also been investigated (McLaren and Dale 1987). These add further costs to stonefruit production. Improvement in preharvest controls would be a significant development.

Some pyrethroid insecticides have important repellent and antifeedant properties useful in pest control in addition to their direct toxicity (Elliot *et al.* 1978). This spectrum of activity provides additional opportunities for pest control. Fluvalinate is a pyrethroid with known contact action against thrips as well as other insects (O'Connor 1987). Penman *et al.* (1986) showed that repellency was an important factor in the activity of fluvalinate on spider mites.

This section investigates two approaches to thrips control on ripe stonefruit. Firstly a trial examines the effectiveness of the current recommended insecticide regime using carbaryl. A second trial investigates the use of fluvalinate (Mavrik Aquaflow 240 g/litre, flowable formulation) at low application rates.

2.2 MATERIALS AND METHODS

2.2.1 THRIPS CONTROL WITH CARBARYL

Ripe peaches and nectarines were sampled for thrips from trees in a stonefruit variety block of the Lincoln College Horticultural Research Area (Block 2, see Appendix 5) during the 1985-86 season. Carbaryl was applied regularly for thrips control (see Appendix 5). Tree variety, number of sample trees, position within the block and sample dates are listed in Table 8.4.

Ten fruit were picked at harvest (local market) below 2 m from each tree and immediately sealed separately in plastic bags and refrigerated (4^{o}C) until they could be examined for thrips.

In the laboratory fruit were examined for adult thrips with the naked eye, and for larvae under a binocular microscope (x 10). All adults were mounted on slides with polyvinyl alcohol (P.V.A.) under coverslips and left for at least 24 hours to clear (Walker and Crosby 1979). All mounted adults were identified to species according to Mound and Walker (1982, 1984). The level of egg infestation was

established by boiling stonefruit skins in lactophenol and aniline blue and examining the skin under a binocular microscope (see Chapter V).

The diameter of each fruit was measured and its surface area determined assuming that a fruit approximated the shape of a sphere. Infestation levels for thrips could thus be expressed as numbers per unit area of skin.

2.2.2 THRIPS CONTROL WITH FLUVALINATE

Field trials were conducted on two peach varieties, 'Redhaven' and 'Flamecrest', within two stonefruit blocks in the Lincoln College Horticultural Research Area, Canterbury, New Zealand.

A. 'Redhaven'

Preliminary experiments assessed fluvalinate activity during the period of peak thrips abundance (see Chapter V and VI) and provided fruit for residue analysis. These were conducted on four adjacent peach trees (var. 'Redhaven') from within a group of 12 in a mixed variety stonefruit block (Block 1). Trees were in their seventh year of fruiting and received no insecticide applications after 1/12/86 other than those described below. Single trees were treated with fluvalinate at 10%, 20%, or full field rate (4.5 g/100 litre) and one tree was untreated. Insecticide was applied to half of the tree (north side) with a motorised back-pack sprayer (Solo Model 423) on 13/1/87, 13 days before harvest. About 5 litres were applied to each half tree (400 trees/ ha).

Ten fruit from the treated half of each of the four trees were harvested at local market maturity (26/1/87). Fruit were picked, placed in separately sealed plastic bags and examined for thrips immediately in the laboratory. Adult thrips (both live and dead) were removed and counted for each fruit. Later they were mounted on slides and identified to species. Egg infestation was established as in Section 2.2.1. Larval infestation was determined using a binocular microscope (x10).

Infestation levels were expressed as numbers per unit area of peach skin as in Section 2.2.1.

Five additional fruit per tree were picked from the fluvalinate treated trees, wrapped in tin foil and deep frozen for later pesticide residue analysis using gas liquid chromatography (A.J. Read, pers. comm.).

Detailed statistical analysis of thrips numbers was not undertaken with 'Redhaven' peaches because replication was inadequate.

B. 'Flamecrest'

Twenty-four trees bearing at least 8 fruit per tree were selected from two adjacent rows of one year old peach trees (var. 'Flamecrest') in a mixed stonefruit block (Block 2). These trees had received no insecticide applications since 27/12/86 other than those described below. The following four treatments were randomly assigned to each of six trees:

1. Untreated. No insecticide application.

2. Carbaryl. (Septan 800, 80% WP, 80 g/100 litre). Applied on 3/2/87, 15 days before harvest and 17/2/87, 1 day before harvest.

3. Fluvalinate. 10% field rate (0.45 g/100 litre). Applied on 3/2/87, 15 days before harvest.

4. Fluvalinate. 5% field rate (0.22 g/100 litre). Applied on 3/2/87, 15 days before harvest.

Insecticide was applied with a hand-pump back-pack sprayer. Trees were sprayed to runoff, about 5 litres per 6 trees (1110 trees/ha). Fruit were harvested at export ripeness (18/2/87) and placed separately in sealed plastic bags.

Samples were placed in lined packing cartons in a cool room at $0^{o}C$ for 19 hours. Thrips numbers were determined as for 'Redhaven' but larvae were not counted.

The remaining fruit were picked, wrapped in tin foil and deep frozen. From these fruit a pooled subsample of five fruit per treatment was analysed for residues.

'Flamecrest' results were analysed using the Kruskel Wallis test with pairwise comparisons of the treatments (Hettmansperger 1984) for total adult and egg counts. Live thrips are the main problem in export produce. Since in these experiments some thrips were killed in the sampling process, no distinction was made between live and dead thrips in the analysis. It is not clear whether reduced numbers of dead thrips is of any practical importance (McLaren and Dale 1987).

2.3 RESULTS AND DISCUSSION

2.3.1 THRIPS CONTROL WITH CARBARYL

The mean numbers of thrips infesting the fruit of nectarines and peaches from a sprayed block are given in Table 8.4. Virtually all fruit was infested with adults, eggs and larvae. About 60% of adults were still alive, although most larvae were dead. Almost all adult thrips were identified as *T. obscuratus*.

This fruit was destined for the local market where tolerance limits for thrips on fruit are not as severe as are export. Thrips numbers increase on the ripening fruit (Chapter V), so that local market fruit may have more thrips than export market fruit because it is riper when picked.

These results indicate the importance of correct timing for insecticides such as carbaryl which have a short effective period. Where there are many stonefruit varieties in the same block, as in this trial, and the whole block is sprayed at one time, differing harvest dates make timing of insecticide applications difficult. The short period of effectiveness of carbaryl for thrips control means that there are times when reinfestation can occur. This problem may be overcome by increasing the number of insecticide applications or planting trees with similar harvest dates.

TABLE 8.4: MEAN NUMBER OF THRIPS ON SPRAYED STONEFRUIT AT HARVEST, WITH TREE POSITION AND SAMPLE DATE, BLOCK 2, LINCOLN COLLEGE HORTICULTURAL RESEARCH AREA.

			PER FRUIT						PER MM^2					
	Position*	Sample	Adults		Eggs		Larvae		Adults		Eggs		Larvae	
			$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.
PEACHES														
Redhaven	R7B2T5&6	3/2/86	6.3	9.84	29.5	52.8	1.8	1.8	0.080	0.119	0.379	0.623	0.020	0.018
Fayette	R9B1T18	11/3/86	2.9	3.1	2.5	3.4	2.4	2.5	0.019	0.019	0.017	0.025	0.016	0.016
Fairtime	R10B3T8	27/3/86	3.7	3.6	7.2	6.7	0.8	1.5	0.025	0.022	0.048	0.041	0.006	0.010
NECTARINES														
Flavourtop	R2B2T6&7	24/2/86	7.3	6.6	18.4	22.3	0.3	0.5	0.026	0.028	0.020	0.032	0.0	0.0
Autumn Grand	R6B3T6&7	21/3/86	2.6	3.0	2.0	3.4	0.0	0.0	0.057	0.050	0.153	0.179	0.002	0.004

* R = Row, B = Block, T = Tree

However, even when field treatments of carbaryl are timed to ensure maximum thrips control they do not give complete control of adult and larval thrips on stonefruit (McLaren and Dale 1987).

2.3.2 THRIPS CONTROL WITH FLUVALINATE

On'Redhaven' peaches all treatments of fluvalinate reduced the number of thrips adults, eggs and larvae in comparison with the untreated tree (Figure 8.2). Adults and eggs were sampled from fruit of all treatments, but there were no live adults or larvae on fruit treated at the full rate of fluvalinate. Adults and dead larvae only were found on fruit treated with 20% field rate, and only one live larva was found on all fruit treated with 10% field rate. All adult thrips were identified as *T. obscuratus* females except for one male. This preliminary experiment suggested that even lower rates of fluvalinate could be considered in the subsequent trial.

Adult and egg counts for'Flamecrest' peaches (Figure 8.3) had high standard deviations due to zero counts within the samples, but the Kruskel-Wallis test showed significant differences between treatments for total adults ($p<0.025$) and eggs ($p<0.005$). Significant differences between rank sums of treatments at $p<0.05$ are shown in Table 8.5. There was no significant difference between infestations on fluvalinate (5%) treated, carbaryl treated, and untreated fruit. Fluvalinate (10%) applied once before harvest was significantly more effective at reducing the total number of adults and eggs than two carbaryl applications at full rates. Adults were identified as *T. obscuratus* females (68), males (4) and *Thrips tabaci* females (21).

TABLE 8.5: RANK SUMS FOR THRIPS COUNTS ON FLAMECREST PEACHES AT HARVEST.

TREATMENTS	ADULTS	EGGS
Untreated	116 A*	116 A
Carbaryl	79 A	89 A
Fluvalinate 5%	70 AB	69 AB
Fluvalinate 10%	35 B	26 B

* letter indicates absolute differences of rank sums at $p<0.05$.

FIGURE 8.2: MEAN NO. THRIPS ON 'REDHAVEN' PEACHES HARVESTED FOR LOCAL MARKET (CI=0.05).

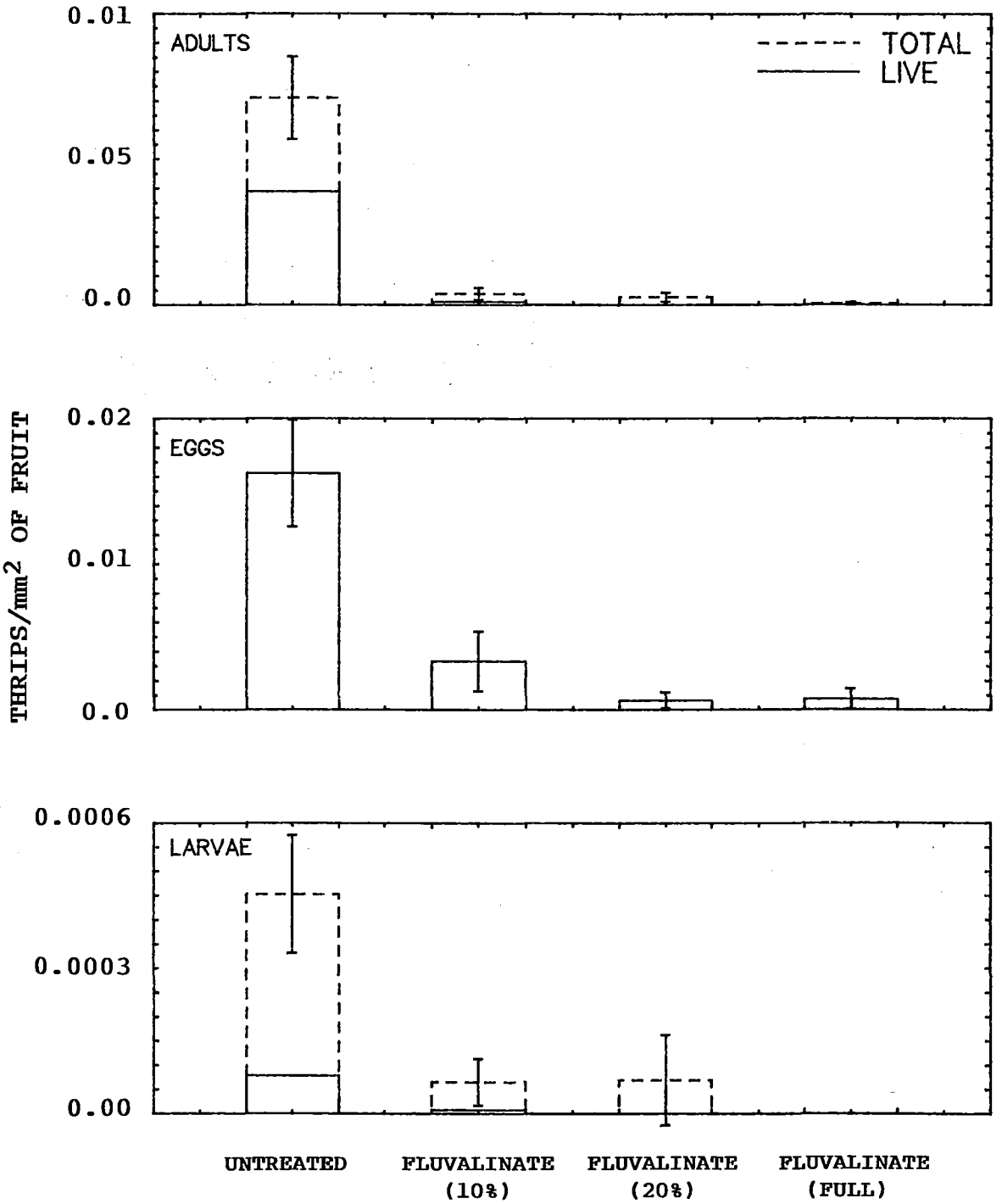
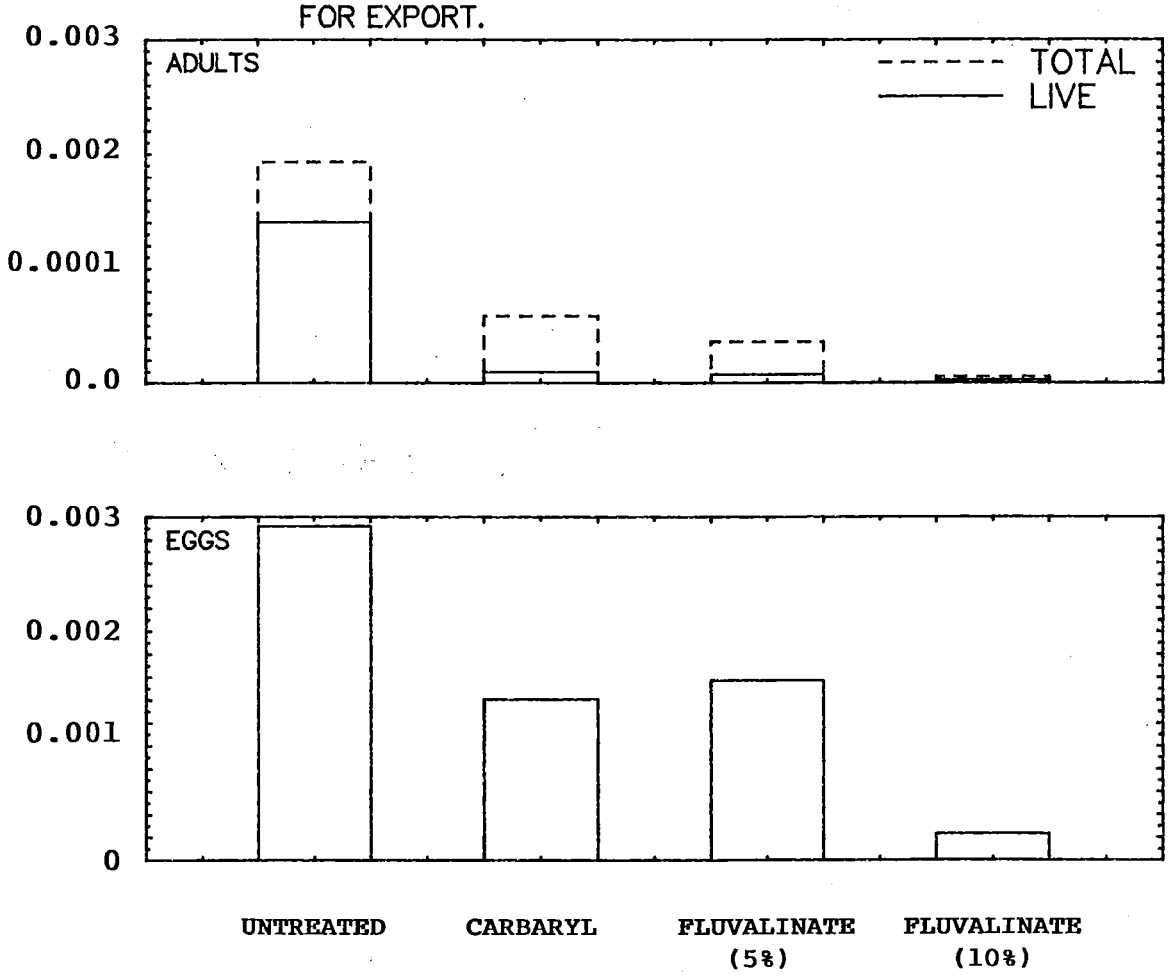


FIGURE 8.3: MEAN NO. THRIPS ON 'FLAMECREST' PEACHES HARVESTED FOR EXPORT.



The low application rates of fluvalinate and previous evidence of repellency with mites (Penman *et al.* 1986) all suggest that repellency is of greater importance than direct toxicity in reducing thrips infestation on peach fruit. No measure of direct toxicity was obtained in these experiments. Eggs are a possible source of export contamination, and numbers were higher in the carbaryl treatments than in fluvalinate (10%) (Table 8.5). This suggests that carbaryl may not have been effective in limiting oviposition by thrips throughout fruit maturity. Since carbaryl has a short period of effectiveness, thrips may oviposit on fruit between treatments. Fluvalinate (10%) applied 15 days before harvest remained effective in reducing total egg numbers with a single application. One important feature of carbaryl reported by McLaren (1985) is its ability to kill thrips after several days in the coolstore. This was not taken into consideration in this trial, as fruit was kept in the coolstore for only 19 hours after harvest.

Residue levels of fluvalinate detected from sample fruit for the different treatments are found in Table 8.6. In New Zealand present maximum residue levels (MRL) for fluvalinate on stonefruit are nil at harvest. Fluvalinate is registered for use over the flowering period. MRL's for use of fluvalinate overseas are uncommon, but in France there is a seven-day withholding period on peach with a MRL of 0.1 ppm (A.J. Read pers. comm.). Residue levels detected in these trials at all concentrations on both varieties fell well below this figure.

TABLE 8.6: DETECTABLE RESIDUE LEVELS OF FLUVALINATE ON RIPE PEACH FRUIT.

VARIETY	TREATMENT	RESIDUE mg/kg*
Redhaven	Full fluvalinate	0.02
Redhaven	20% fluvalinate	0.03
Redhaven	10% fluvalinate	none detected
Flamecrest	10% fluvalinate	0.01
Flamecrest	5% fluvalinate	0.02

* calculated on the whole fruit including the stones. Limit of detection was estimated to be 0.01 mg/kg.

Higher thrips numbers were found on 'Redhaven' than on 'Flamecrest' peaches because they were harvested at peak thrips flights and were more mature. In Chapter V it was shown that thrips infestation of fruit increases with fruit maturity. 'Flamecrest' peaches were harvested after peak thrips activity and at export maturity. Both these factors result in lower thrips numbers than on 'Redhaven'. In spite of this,

treatment of'Flamecrest' with 10% field rate of fluvalinate gave significantly greater control than the normal carbaryl programme.

Thrips are active fliers and are likely to migrate into orchards throughout the period of fruit maturity. Experiments using single or half-tree treatments did not simulate whole-block applications accurately, in that trees were subjected to higher infestation pressures than usual. The possible repellent action of fluvalinate may be enhanced by larger-scale applications. Given appropriate residue clearances, fluvalinate may provide a low rate, single-application strategy for preharvest thrips control.

2.4 SUMMARY

Several varieties of ripe stonefruit picked at maturity for the local market and which received periodic applications of carbaryl prior to harvest were infested with thrips adults, eggs and larvae.

T. obscuratus was the dominant thrips species on sprayed stonefruit. *Thrips tabaci* were also common on'Flamecrest' peaches in one trial.

The use of fluvalinate at low application rates for preharvest control of thrips on peach fruit was investigated. Peaches were sampled at local market maturity ('Redhaven') and export market maturity ('Flamecrest') for thrips. Low application rates of fluvalinate (20% to 5% of field rates) reduced thrips infestation on both varieties. On 'Flamecrest' one application of fluvalinate at 10% field rate, 15 days before harvest, was more effective at reducing thrips infestation than the current recommended spray programme.

CHAPTER IX

GENERAL DISCUSSION

The overall objective of the work in this thesis was to investigate the biology and ecology of *T. obscuratus* so that rational decisions could be made concerning the management of this species, especially in relation to stonefruit. Specific aims within this objective are listed in Chapter I.

The requirements for a good pest management programme includes a biological data base, a management data base and a variety of management techniques (Hoyt *et al.* 1983). The research in this thesis has been primarily concerned with the biological data base, although some other areas have been investigated. In this chapter I will review the pest management of the New Zealand flower thrips on stonefruit in Canterbury in relation to previous research and knowledge gained from the research in this study. The importance of this study can then be evaluated and future areas for research identified.

1 PEST IDENTIFICATION

One of the necessary prerequisites for pest management is the identification of the pest concerned. Mound and Walker (1982) have provided good descriptions and keys for the identification of *T. obscuratus* adults, but present descriptions of the immature stages are inadequate to distinguish between species or larval instars.

In this study, the development of a laboratory rearing method enabled larvae and pupae collected in the field to be reared to adults for identification. This proved invaluable for the identification of immature thrips infesting stonefruit flowers and fruit as well as for determining the host plants and pupation sites of *T. obscuratus.*

Good descriptions of the immature stages of *T. obscuratus* are still needed for accurate pest identification without having to resort to tedious laboratory rearing. With the rearing methods developed in this study a good supply of immature stages can be procured and isolated from accurately identified *T. obscuratus* parents, so that diagnostic descriptions for the immature stages can be prepared.

2 BIOLOGICAL DATA BASE

2.1 BIONOMICS OF THE NEW ZEALAND FLOWER THRIPS

2.1.1 LIFE CYCLE

As recently as 1985, Walker (1985) stated:

> 'Little is known about the biology of the New Zealand flower thrip(s). In spite of the large numbers of adults seen, larvae are difficult to find. The life cycle probably takes about one month, commencing with microscopic eggs laid in plant tissue. There are four immature stages, which are white to creamy in colour. The first two are active feeding stages, the third an inactive prepupa, and the final a pupa, which probably rests in the ground before the adult emerges.'

Reported ovipostion sites for *T. obscuratus* are mostly in flowers but also in leaves. In this study large numbers of eggs were also found in the skin of ripe stonefruit. This study contains the first records of habitats for accurately-identified *T. obscuratus* larvae. Larvae were found predominantly in flowers but also on the fruit of stonefruit. The first records of pupation sites for *T. obscuratus* in the field, in leaf litter and soil beneath flowering cabbage trees, are reported.

The development of a laboratory rearing method for *T. obscuratus* has enabled the basic demographic parameters to be examined. Aspects of reproduction, fecundity, requirements for oviposition and development, development rates, temperature thresholds, thermal constants, and lifespan for *T. obscuratus* are detailed in Chapter III. These data are among the most extensive established for a flower thrips species. Temperature is the most important factor in determining the rate of development, although diet is also important. Pollen is necessary for sustained egg production, and larval development was fastest and mortality lowest for thrips supplied with diets including pollen. Humidity was identified as an important factor in pupation, but further research is needed to examine the relationship between soil moisture and pupal mortality. The life cycle and parameters of reproduction and development for *T. obscuratus* are consistent with those established for other flower-inhabiting thrips (see Andrewartha 1935, Bailey 1938, Quayle 1938, Laughlin 1970, Murai and Ishii 1982, Kirk 1984, 1985a).

The laboratory rearing method, which was adapted from Murai and Ishii (1982), was simple, flexible and facilitated the development of *T. obscuratus* with low mortality. The method is probably suitable for a number of thrips species. Larvae collected in the field and reared to adults by this method included *Scirtothrips inermis, Ceratothrips frici, Frankliniella occidentalis, Thrips australis* and *Thrips tabaci.*

2.1.2 SEASONALITY

Where host plant flowers are available, adults and larvae of *T. obscuratus* are found throughout the year. In this study it was established that there is no reproductive diapause, so continuous generations occur. In Canterbury there are probably between 6-8 generations per year.

It was found that there was a broad pattern of seasonal abundance in Canterbury over several seasons. Thrips numbers were lowest in winter and low in spring, but increased gradually during summer. Numbers peaked in midsummer but declined suddenly in mid to late January. Numbers remained moderate to low throughout late summer and autumn. Seasonal abundance could be largely explained by the interrelationship of temperature, soil moisture and availability of host plants. This seasonal pattern and its causative factors are similar to those described for the multivoltine, polyphagous, flower-inhabiting *Thrips imaginis* in Australia (Evans 1934, Andrewartha and Steele 1934).

2.2 HOST PLANT-PEST INTERACTIONS

2.2.1 HOST PLANTS

T. obscuratus is known to be highly polyphagous, being collected from a wide range of introduced and endemic plants, not only on flowers but also on leaves, fruit and leaf litter. However the range of plants it uses for breeding has not been clearly established (Mound and Walker 1982).

The development of a rearing technique for *T. obscuratus* enabled identification of larvae collected in the field so that breeding hosts can be established. *T. obscuratus* larvae were taken from 49 species of plants. The polyphagous behaviour of *T. obscuratus* is therefore clearly defined, and was evident among both endemic and introduced plant species. Larvae were found predominantly in flowers but also on the fruit of stonefruit.

Adults of *T. obscuratus* fed on the ripe fruit of stonefruit where they laid eggs from which larvae hatched. Although larvae can reach maturity on a diet of peach fruit and sucrose in the laboratory, it is doubtful that many of the eggs laid in fruit in the field survived to maturity.

Many flower-inhabiting thrips are highly polyphagous (Evans 1932, Watts 1936, Kirk 1985a) but only two; *Frankliniella occidentalis* and *Thrips major*, have been reported from ripe stonefruit (LaRue *et al.* 1972, Pollini and Giunchi 1979).

2.2.2 HOST PLANT SELECTION

Factors involved in host selection by *T. obscuratus* were investigated with field experiments. *T. obscuratus* adults were most attracted to traps painted white without ultra-violet compared to other colours, and traps baited with scents, such as benzaldehyde and anisaldehyde that are common in flowers and fruit, as well as with ethyl nicotinate. These results are similar to those obtained for other polyphagous flower thrips (Walker 1974, Kirk 1984a, b, 1985b) although *T. obscuratus* was less attracted to blue than some species. This may be explained by the scarcity of blue flowers in the New Zealand endemic flora (Lloyd 1985). The attractiveness of thrips to ethyl nicotinate has not been examined outside New Zealand. Apart from one report (Wilson *et al.* 1985), ethyl nicotinate has not been identified from flowers or fruit. The probable general response of polyphagous flower thrips to floral scents (Kirk 1985b) and the structural similarity of ethyl nicotinate to some floral scents, are likely to be implicated in the strong attraction of *T. obscuratus* to ethyl nicotinate.

For *T. obscuratus*, colour and scent are probably important in host selection, including stonefruit flowers and fruit, but the relative importance of each factor at different stages of the host selection process can only be speculated upon. Benzaldehyde is an important component of ripe peach odour (Do *et al.* 1969) and is likely to be important in the host selection of ripe stonefruit by thrips.

2.2.3 FLOWER INFESTATION

Feeding thrips are a source of injury to young nectarine fruit. In New Zealand, McLaren (1986) found that the most severe damage by thrips was done between full bloom and petal fall by *T. obscuratus* adults. This conflicts with overseas reports, which suggest that the most important time for fruit injury is slightly later, between petal fall and shuck fall and is a result of larval feeding (Bailey 1938, LaRue *et al.* 1972, Bournier 1983, Cravedi and Molinari 1984). Nectarines are more susceptible to thrips damage than peaches because they have smooth skin and the floral tissues stick tightly to the developing fruit (Bailey 1938). However, the few quantitative studies of thrips species on stonefruit flowers are inadequate because they do not consider larvae (see Cravedi and Molinari 1984) and there has been no comparison of thrips infestation levels between nectarines and peaches. This study reports the first quantitative samples for thrips adults and larvae in stonefruit flowers.

T. obscuratus was confirmed as the main thrips species inhabiting stonefruit flowers. On unsprayed trees, adults were found in similar numbers throughout flower development but larval numbers peaked at or just after petal fall. As peak larval numbers were about ten times greater than adult numbers, larval feeding was considered to be a significant factor in damage to young nectarine fruit.

Similar numbers of adults and larvae were sampled from nectarine and peach flowers but thrips injury to peach fruit was limited.

2.2.4 FRUIT INFESTATION

In New Zealand *T. obscuratus* infests peach, nectarine and apricot fruit. Little was known about the extent of thrips infestation, the composition of the thrips species and seasonal and varietal influences. The few reports of thrips infesting the fruit of stonefruit overseas are largely anecdotal (see LaRue *et al.* 1972, Pollini and Giunchi 1979). This study reports the first detailed examination of thrips infestation on the fruit of stonefruit.

Thrips adults and larvae sampled from stonefruit were almost all *T. obscuratus* even though other thrips species were present in the orchard. Adults were almost entirely female. Adults, eggs and larvae were most common on ripe fruit, although they were found in low numbers on fruit up to three weeks before harvest. Thrips numbers were higher on peaches than apricots and nectarines. The seasonal variation of thrips numbers on ripe fruit reflected thrips flight patterns rather than varietal differences. Feeding damage to and contamination of fruit by thrips adults, eggs and larvae are important considerations in pest management.

2.2.5 FUNGAL VECTOR

An important aspect of thrips association with plants is their ability to act as vectors of plant pathogens. It is evident that fungal spores can be trapped in the body hairs of many thrips species and transferred to healthy plants (Bournier 1983). Ondrej (1973) gave evidence of *Thrips* spp. as mechanical vectors of *Botrytis fabae*, a pathogen of beans. Brown rot, caused by the fungal pathogen *Monilinia fructicola*, is a disease of both stonefruit flowers and fruit (Atkinson 1971). The presence of brown rot and thrips together on stonefruit flowers and fruit suggested a possible vector relationship. Preliminary laboratory experiments indicated that *T. obscuratus* was a potential vector of *Monilinia fructicola* on flowers (Teulon unpubl.). Since then, Ellis *et al.* (1988) have indicated that *T. obscuratus* is a mechanical carrier of *Monilinia fructicola* spores under laboratory and field conditions.

Further research is needed to determine the importance of the thrips-fungal relationship in terms of crop losses. Research on thrips as fungal vectors in general is limited, and an understanding of this relationship will be important with reference to other thrips species.

2.3 SPATIAL DISTRIBUTION AND DISPERSAL

In this study little effort was made to investigate the distribution of *T. obscuratus* within the host tree, in the orchard or in the surrounding environment, so this is an important area for future research. A knowledge of the spatial distribution of thrips is useful for optimising sampling techniques, studying and modifying control tactics and elucidating economic injury levels (Hoyt *et al.* 1983).

From comparison of traps placed outside and inside stonefruit orchard blocks, thrips seemed to be continually flying into and out of the orchard in search of host plants. Thrips are primarily orchard invaders rather than inhabitants of commercial orchards and populations within orchards were dependent on conditions outside. Future research should focus on the mechanisms initiating immigration into the orchard from host plants outside, the environmental conditions suitable for immigration, the rates of immigration under different conditions, the distance that thrips will fly to invade orchards and the factors arresting thrips once they enter the orchard.

An understanding of thrips movements on individual trees, within and between orchards maybe especially significant if *T. obscuratus* proves to be an important vector of *Monilinia fructicola.*

The distribution of *T. obscuratus* on a wider scale has important consequences for pest management. As *T. obscuratus* is endemic and largely restricted to New Zealand, export fruit requires stringent control procedures. It is important to verify reports of the presence and distribution of *T. obscuratus* in Australia. This may influence the extent to which quarantine barriers are placed against the entry of infested horticultural produce, including stonefruit, into Australia, and thus influence the control strategies for *T. obscuratus* in New Zealand.

3 MANAGEMENT DATA BASE

3.1 ECONOMIC INJURY LEVELS

As export fruit must be largely free from pest damage and contamination, economic injury levels for thrips on stonefruit are extremely low. Work by McLaren (1980-86), which was confirmed by research in this thesis, has shown that economic damage by thrips during flowering occurs at very low levels of infestation. This is also the case for thrips infesting nectarine flowers overseas (Allman 1948b, Bournier 1970, Cravedi *et al.* 1983). As the New Zealand flower thrips is flying throughout the season from numerous hosts into the orchard it is a reasonable assumption, and experimental data verifies this, that thrips are always present in numbers sufficient to cause economic damage to stonefruit flowers and fruit. Therefore determination of economic or action thresholds is almost irrelevant, as the economic injury level is always exceeded. Control is needed for thrips on export crops all the time.

The level of damage acceptable to the local market is usually higher than for exports. Once standards for fruit quality have been developed for the local market (Quirke 1988), the development of economic injury levels may be worthwhile.

3.2 MONITORING AND SAMPLING

In this study a number of sampling methods were developed. These included methods to determine thrips phenology and numbers on stonefruit flowers and fruit and the pattern of thrips flights throughout the season. The development of a technique for sampling thrips eggs from the fruit skin was of particular importance and may be applicable for other thrips species and in other plant tissues. White without ultra-violet was found to be the most appropriate colour for trapping *T. obscuratus*, and ethyl nicotinate was a powerful attractant for *T. obscuratus* when numbers were low.

The methods described in this study could be used, and in some cases adapted, for research on thrips dispersion and immigration within the orchard.

The development of thrips monitoring techniques for pest management is not a priority for reasons stated above. Thrips population levels on stonefruit flowers and fruit are always at or above the economic injury level, so sampling is not necessary.

3.3 MODELING AND PREDICTION

Phenological models are useful for predicting the timing of events in an insect's life-cycle for pesticide applications or monitoring assesments. Although many of the basic biological parameters for this type of model have been established for *T. obscuratus* in this study, these types of models may be of limited value because of the short life-cycle, overlapping generations and low economic thresholds of this thrips.

A within-season model incorporating soil moisture and pupal mortality would be valuable for establishing the time when thrips numbers decline in midsummer. This would identify fruit varieties likely

to be less infested with thrips and more suitable for export. More clearly defining the relationship between soil moisture and pupal mortality would be a significant area for future research.

Between-season models such as developed by Davidson and Andrewartha (1948b) for establishing peak numbers per season would have little application to *T. obscuratus* pest management. Unless peak thrips numbers are much lower than those recorded in this study, peak thrips numbers would always be higher than the economic injury level.

4 THRIPS CONTROL TACTICS

4.1 CHEMICAL CONTROL

The low economic injury levels and the inadequacy of other control tactics has led to a reliance on chemical controls for thrips on stonefruit. This has been made worse by insufficient knowledge of the biology and ecology of *T. obscuratus*. Chemical control is likely, however, to remain the main strategy for thrips control on stonefruit.

In this study field trials investigated the effectiveness of recommended pesticide schedules for thrips control during flowering and at harvest, and new chemical control methods were developed.

Applications of insecticides, with low bee toxicity to nectarine flowers at full bloom in addition to the normal spray programme reduced the numbers of thrips infesting nectarine flowers and the level of thrips damage to nectarine fruit. This research has led to the registration of the synthetic pyrethroid insecticide fluvalinate for thrips control during flowering in New Zealand and it is likely to be applicable to thrips control on stonefruit outside New Zealand. The effectiveness of fluvalinate applied at low rates at harvest indicates a need for further research aimed at reducing application rates of fluvalinate during flowering.

Significantly, fluvalinate applied at low application rates (10% of field rate), reduced thrips numbers on ripe fruit more effectively than the recommended spray programme. Repellency was considered to be an important component of thrips control with fluvalinate.

Future research on chemical control of thrips on stonefruit must concentrate on insecticide applications compatible with the control of other pests and the effect on beneficial invertebrates. For example, aphicides applied during flowering coincide with applications for thrips control. Some insecticides (e.g., fluvalinate, O'Conner 1987) are effective against thrips, aphids and mites. The effect of insecticides applied for thrips control on predator mites has been neglected. This is a particularly important area for research, because of the reduction of available miticides for pest control (R. Chapman pers. comm.). The effect of low concentrations of fluvalinate on predator mite populations should be investigated.

Viable methods for decreasing insecticide usage are important for a number of reasons (Luckman and Metcalf 1982, Thomson and Suett 1986) but the use of fluvalinate at low application rates may have particular significance for thrips control. Repellency may be useful in the control of thrips that have a low sensitivity to many of the commercially available insecticides (e.g. *Frankliniella occidentalis*, C. Payne

pers. comm.; and *Thrips palmi*, Matsuzaki (1982) in Kawai and Kitamura (1987)), or where the use of insecticides is restricted by the presence of beneficial invertebrates (Hussey 1985).

4.2 ATTRACTANTS

Field experiments in this study have shown that *T. obscuratus* is more strongly attracted to ethyl nicotinate than to ripe peaches and other known thrips attractants. Ethyl nicotinate may be useful as a control tactic for reducing thrips numbers on stonefruit flowers and fruit by attracting thrips away from the crops. This type of control may be particularly useful for reducing thrips numbers on fruit in the confined area of the packing shed. Future research is needed to determine if this approach is feasible. Important considerations include the concentration levels of ethyl nicotinate formulations and the most efficient trap type for optimum thrips control.

4.3 BIOLOGICAL CONTROL

Although several predators (but no parasites) have been identified for *T. obscuratus* (Mound and Walker 1982), Walker (1985) stated that there is little prospect of biological control because of the constant supply of thrips reinfesting flowers and fruit from host plants close by. There are, however, areas where research on biological control for thrips may prove profitable.

The thrips predators, *Spilomena* spp. were not observed preying on thrips on either stonefruit flowers or fruit in this study. Given suitable conditions, for example the provision of breeding sites within the orchard, these wasps may be useful as biological control agents. Research is needed to examine the importance of this predator in relation to *T. obscuratus* in general, and then to investigate its application for use in stonefruit pest management.

The first records of parasitic nematodes for *T. obscuratus* are reported in this study. Nematodes sterilised females and were tentatively identified as *Howardula aptini* (Sharga). It has been suggested that this nematode may be used for the biological control of thrips overseas (Reddy *et al.* 1982), but because of the short generation time and high fecundity of *T. obscuratus*, parasitism may not affect the overall population size. Future research should identify the nematode and its effect on thrips populations. This should indicate its future applicability for biological control.

4.4 HOST PLANT RESISTANCE

Plant resistance to pests is often the result of fortuitous differences in pest preferences among existing horticultural varieties rather than resistance features actively developed. In this study, apart from differences between stonefruit types, there was little evidence of any variety with an ability to withstand thrips infestation. Kemp (1959) found that some nectarine varieties sometimes showed more severe symptoms than others, but these varieties are not grown commercially today. There is little mention of host plant resistance for thrips control on stonefruit overseas. As economic injury levels for *T. obscuratus* on

export stonefruit are extremely low, it is unlikely that plant resistance will be an important tactic in pest management of this species.

4.5 CULTURAL CONTROL

4.5.1 CULTIVATION

Cultivation of nectarine blocks before flowering has been found to reduce the levels of fruit damage both overseas and in New Zealand (LaRue *et al.* 1972, Anon. 1979). This is a result of the destruction of hosts plants so that there are fewer thrips in the orchard at flowering. If cultivation is carried out during flowering the disturbed thrips migrate into the trees and fruit damage is increased (Anon. 1979).

4.5.2 FLOWERING AND HARVEST DATES

Generally all nectarines varieties flower at a similar time, when *T. obscuratus* is active within the orchard. Therefore there is little chance of selecting nectarine varieties to avoid thrips infestation at flowering.

There is a wide range of harvest dates for nectarine and peach varieties from December to April. In this study distinct seasonal fluctuations in the number of *T. obscuratus* were found within stonefruit blocks in Canterbury. The initial choice of stonefruit varieties in accordance with harvest dates has an important bearing on the level of thrips infestation of ripe fruit in Canterbury. Fruit harvested in December and January is likely to be more heavily infested with thrips than fruit harvested in February, March and April. This was verified by field data. Therefore, selection of stonefruit varieties that ripen after January would help thrips control.

4.5.3 ALTERNATE HOST REMOVAL

This study identified many breeding hosts for *T. obscuratus*. The removal of all host plants from the vicinity of stonefruit orchards is impractical. However, in late winter and early spring there are few hosts of *T. obscuratus* flowering. Removal of these hosts should significantly reduce the levels of thrips infesting nectarine flowers and thus reduce fruit damage. The distance that thrips fly to invade orchards is an important consideration.

T. obscuratus adults were found on flowers of willow trees used as shelter for nectarine blocks. The replacement of willow shelter with trees (e.g. poplar) not providing feeding sites for *T. obscuratus* adults may reduce the level of thrips infestation of nectarine flowers.

4.6 POSTHARVEST DISINFESTATION

This was not an area of research in this study. Nevertheless, data gained in rearing experiments from this study has proved valuable for estimating times of full egg hatch in controlled conditions in postharvest research (B. Stephenson, pers. comm.). In the field insecticide treatments have not given complete control of thrips on the fruit of stonefruit (McLaren and Dale 1987). Even with the improved

spray programme developed in this study, some thrips remained on ripe fruit. Therefore, there is a continuing need for research into post-harvest control of thrips on stonefruit.

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LIST OF APPENDICES.

APPENDIX 1. TAXONOMIC STATUS OF THE THYSANOPTERA REPORTED IN THIS STUDY.

Sub Order TUBULIFERA

PHLAEOTHRIPIDAE

Subfamily PHLAEOTHRIPINAE

Apterygothrips collyerae Mound & Walker

Haplothrips kurdjumovi Karny
Haplothrips leucanthemi (Schrank)
(= *H. niger*)
Haplothrips niger (Osborn)
Haplothrips subtilissimus (Haliday)
Haplothrips verbasci (Osborn)

Teucothrips disjunctus (Hood)

Sub Order TEREBRANTIA

Family AEOLOTHRIPIDAE

Aeolothrips fasciatus (Linnaeus)

Desmidothrips walkerae Mound

Family HETEROTHRIPIDAE

Heterothrips spp.

Family THRIPIDAE

Subfamily PANCHAETOTHRIPINAE

Heliothrips haemorrhoidalis (Bouché)

Hercinothrips femoralis (Reuter)

Subfamily THRIPINAE

Tribe SERICOTHRIPINI

Scirtothrips inermis Priesner

Tribe CHIROTHRIPINI

Chirothrips manicatus (Haliday)

Limothrips cerealium (Haliday)

Tribe THRIPINI

Subtribe APTINOTHRIPINA

Anaphothrips obscurus (Muller)

Subtribe THRIPINA

Ceratothrips ericae (Haliday)
Ceratothrips frici (Uzel)

APPENDIX 1. continued.

Frankliniella intonsa (Trybom)
Frankliniella minuta (Moulton)
Frankliniella moultoni
(= *F. occidentalis*)
Frankliniella occidentalis (Pergande)
Frankliniella tritici (Fitch)

Kakothrips robustus
(= *K. pisivorus* Westwood)

Taeniothrips inconsequens (Uzel)
Taeniothrips meridionalis Priesner

Thrips angusticeps Uzel
Thrips australis Bagnall
Thrips flavus Schrank
Thrips fuscipennis Haliday
Thrips hawaiiensis (Morgan)
Thrips imaginis Bagnall
Thrips major Uzel
Thrips meridionalis ?
Thrips obscuratus (Crawford)
Thrips palmi Karny
Thrips phormiicola Mound
Thrips simplex (Morison)
Thrips tabaci Lindeman
Thrips vulgatissimus Haliday

APPENDIX 2. EXPORT PRODUCE CONTAMINATED BY THE NEW ZEALAND FLOWER THRIPS.

Species	Common Name	Plant Part	Reference*
Anemone sp.		flower	MAFW
Actinidia deliciosa	kiwifruit	fruit	MAFA, Mound & Walker 1982
Asparagus officinalis	asparagus		Townsend & Watson 1984
Berzelia sp.		flower	MAFW
Boronia megastigma		flower & stem	MAFL
Cynara scolymus	globe artichoke		MAFL
Fragaria x ananassa	strawberry	fruit	MAFW
Fragaria chiloensis		fruit	MAFW
Gypsophila sp.		flower	MAFL
Leptospermum sp.		flower	MAFW
Leucadendron sp.		leaf, stem	MAFL, MAFW
Leucospermum sp.		stem	MAFW
Liastris sp.		flower	MAFA
Nerine sp.		flower	Carpenter 1987, MAFW
Phylica sp.		flower	MAFL, MAFW
Protea sp.		flower	MAFW
Prunus armeniaca	apricot	fruit	MAFW
Prunus persica	peach	fruit	MAFA, MAFW
Prunus persica	nectarine	fruit	MAFW
Pseudopanax sp.		flower	MAFW
Rubus idaeus	red raspberry	fruit	MAFW
Rubus phoenicolasius	wineberry		MAFA
Rubus sp.		fruit	MAFW
Thryptomene		flower	MAFL, MAFW
Vaccinium sp.		fruit	MAFW
Zantedeschia sp.		flower	MAFA
	orchid		MAFL

* MAFA= MAFQual Plant Plant Protection Centre, Lynfield, Auckland
MAFL= MAFQual Plant Protection Centre, Levin
MAFW= MAFQual Head Office, Wellington

APPENDIX 3. AN EXTRACTION METHOD FOR SAMPLING SMALL INSECTS FROM VEGETATION.

Extraction of small invertebrates from fresh vegetation samples can be tedious and lead to inaccurate determination of populations. For example, the New Zealand Flower Thrips, *T. obscuratus*, occurs in low densities over the flowering period of stonefruit. Visual searches of flowers give inaccurate population information. Accordingly a method was developed to extract thrips from flowers, which can be adapted for extraction of other small invertebrates.

For insect species that hide inside crevices, such as leaf sheaths or deep inside compact inflorescences, a dry, dynamic extraction method that stimulates them to crawl out of the vegetation is most efficient (Lewis 1973). Shirck (1948) developed an extraction method based on heating vegetation over funnels. It proved suitable for extracting thrips from onion plants and seed heads, lucerne, clover and bean plants (Shirck 1948). The method described here is similar to Shirck's but makes use of commonly available materials and is easily constructed.

A collection cylinder (100 long x 81mm dia.) was made by removing both ends of a one pint plastic pottle (Plastic Moulding Co. Hamilton, N.Z.). One end was enclosed with fine nylon gauze material. A petri dish (Gibco N.Z. Ltd. Auckland) was used as a lid to complete the cylinder (Figure 1).

The funnel was made from the neck and 20mm of the cylinder of a one litre plastic flask (dia. 79mm) (Plastic Moulding Co. Hamilton, N.Z.). The inside neck of the funnel was painted with Fluon (Whitford Plastics Ltd. Cheshire, England) to provide a slippery surface that facilitated insects falling into the collecting jar. A wire gauze square (mesh size, 2 x 2mm) was placed on a convenient lip inside the neck of the funnel to prevent plant material from falling through to the collecting jar (Figure 1). The collecting container was a 50ml glass pomade jar containing 15 mls of A.G.A. solution (60% ethanol, glycerol and acetic acid, in the ratio of 10:1:1). A.G.A. is a storage solution for thrips (Mound and Walker 1982). The collecting cylinder fitted snugly over the cylindrical portion of the funnel and was prevented from slipping further by another convenient lip. The funnel also fitted snugly into the collecting jar.

In the field flower samples were placed inside the collection cylinder and the lid positioned. In the laboratory the lid of the collection cylinder was removed and replaced by the funnel; the whole device was then inverted over the collecting jar.

The collection cylinder and funnel with collecting jar was then placed within an incubator at 50^{o}C. With heat both adult and immature thrips left the dehydrating flowers and were trapped in the A.G.A. solution in the collecting jar.

Table 1 details three calibration experiments using flowers collected from cherry and nectarine trees at full bloom and field collected female or male thrips. Twenty cherry or ten nectarine flowers were placed in each collection cylinder. Ten active adult thrips were added to half the cylinders (Treatment A), and no thrips to the other cylinders (Treatment B). All collection cylinders with funnel and collecting jar were placed in an incubator at 50^{o}C for 24 hours.

APPENDIX 3. continued.

Percentage recovery was established using the following equation:

$$\% \text{ thrips recovered} = \frac{\text{no. recovered Treat. A - no. recovered Treat. B}}{\text{no. added Treat. A}} \times \frac{100}{1}$$

These results showed that this method was between 80 and 100% efficient for recovery of adult thrips from stonefruit flowers.

TABLE 1. THE EFFICIENTCY OF THRIPS RECOVERY FROM CHERRY AND NECTARINE FLOWERS BY HEAT EXTRACTION.

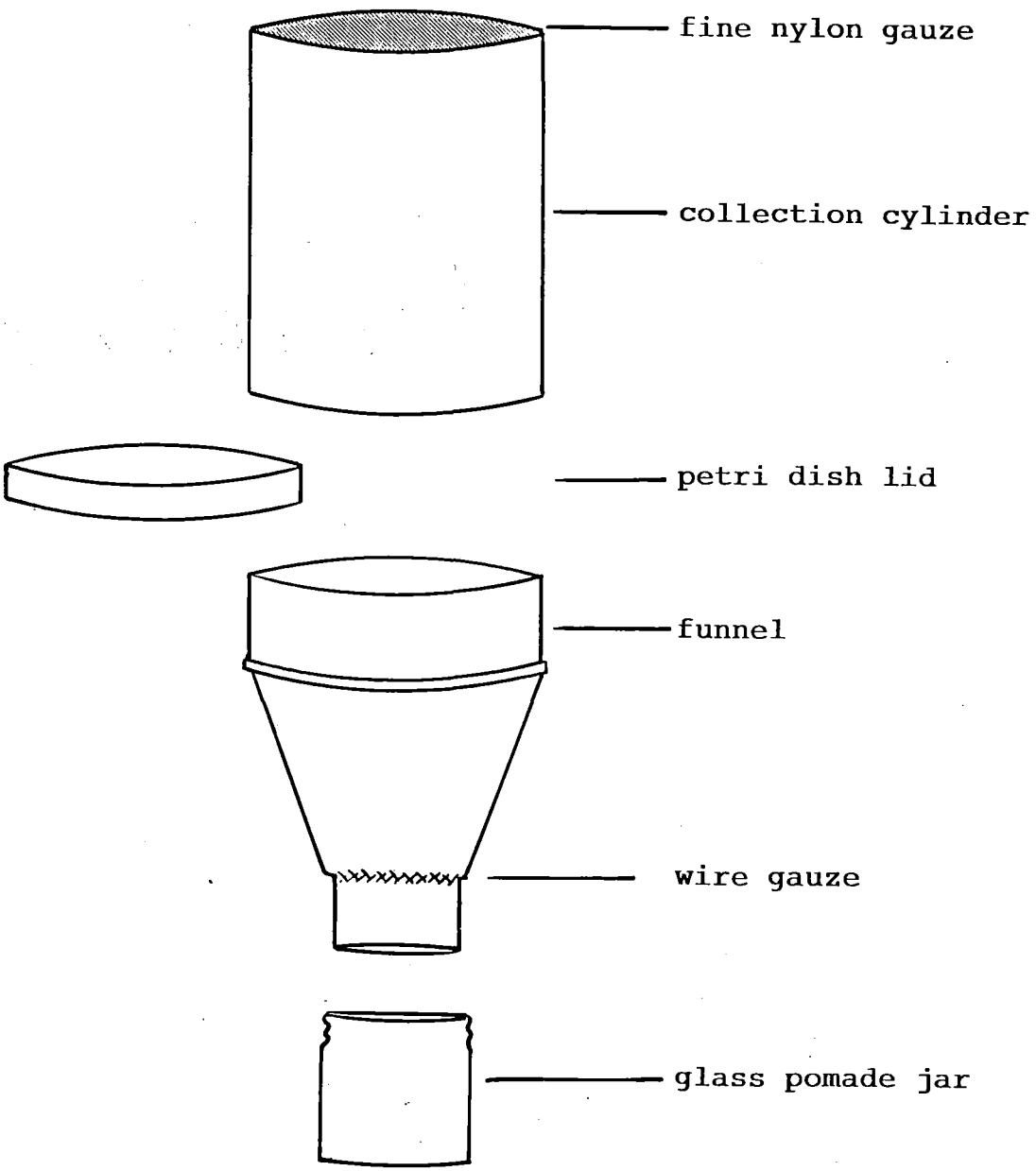
	Treatment A		Treatment B	
Replicate	Thrips added	Thrips recovered	Thrips* recovered	% recovered
1. Cherry flowers female thrips				
1	10	12	1	
2	10	11	0	
3	10	11	1	
4	10	11	1	
5	10	9	1	
Total	50	54	4	100
2. Cherry flowers male thrips				
1	10	11	2	
2	10	6	0	
3	10	10	0	
Total	30	27	2	83.3
3. Nectarine flowers female thrips				
1	10	6	0	
2	10	8	0	
3	10	9	0	
4	10	9	0	
5	10	7	0	
6	10	9	0	
7	10	9	0	
Total	70	58	0	82.9

All thrips recovered were identified as *Thrips obscuratus* except for one *Thrips australis* female in experiment three.

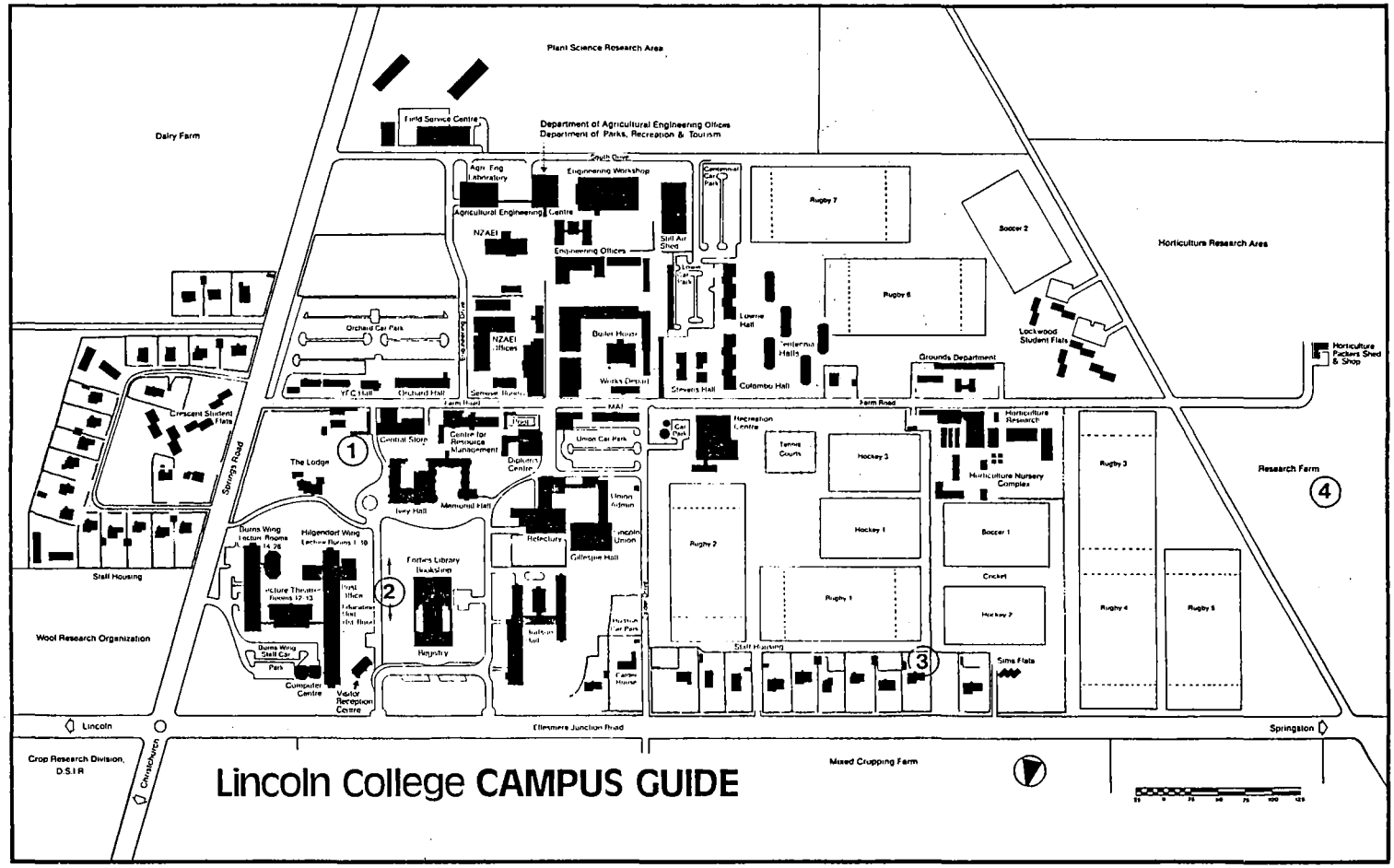
* Includes only those of the sex tested.

APPENDIX 3. continued.

Figure 1. Apparatus for extraction of thrips from vegetation by heat.



APPENDIX 4. THE LINCOLN COLLEGE CAMPUS



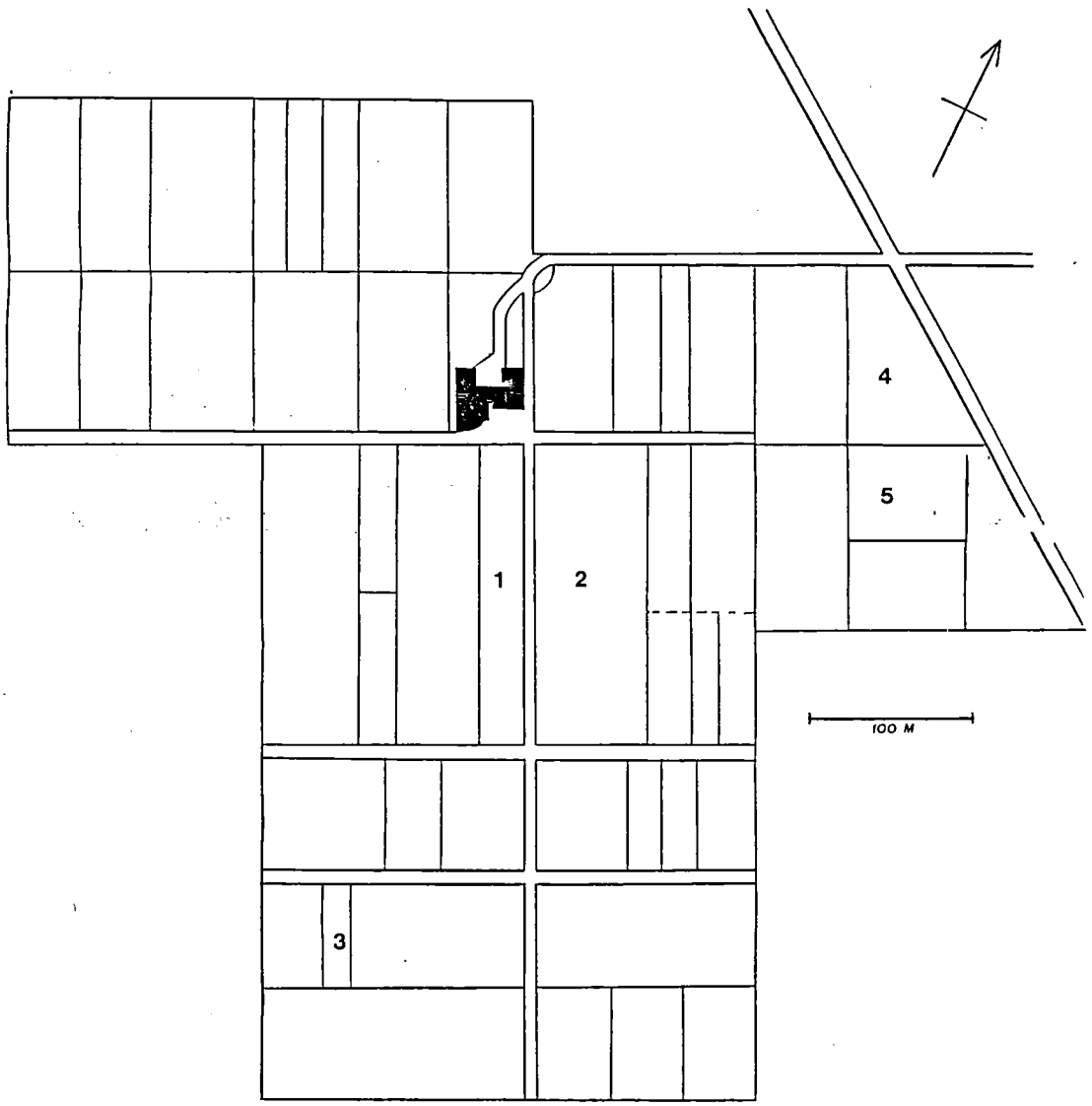
KEY: 1 FORMAL GARDEN

2 YOSHINO CHERRY TREES

3 SINGLE UNSPRAYED NECTARINE TREE

4 METEOROLOGICAL STATION

APPENDIX 5. THE LINCOLN COLLEGE HORTICULTURAL RESEARCH AREA



Key:
1 BLOCK 1
2 BLOCK 2
3 STONEFRUIT TREES OF THE ORGANIC AREA
4 OUTSIDE TRAPS
5 OUTSIDE TRAPS AND ATTRACTION EXPERIMENTS

APPENDIX 5 continued.

THE LINCOLN COLLEGE HORTICULTURAL RESEARCH AREA.

Location: Latitude 43° 38S, latitude 172° 30E.

Height above sea level: 12m.

Surrounding land use included: mixed cropping and pasture. The research area consisted of 18.8 hectares with a wide variety of berryfruit, grape, pip and stonefruit, and vegetable research and demonstration plots.

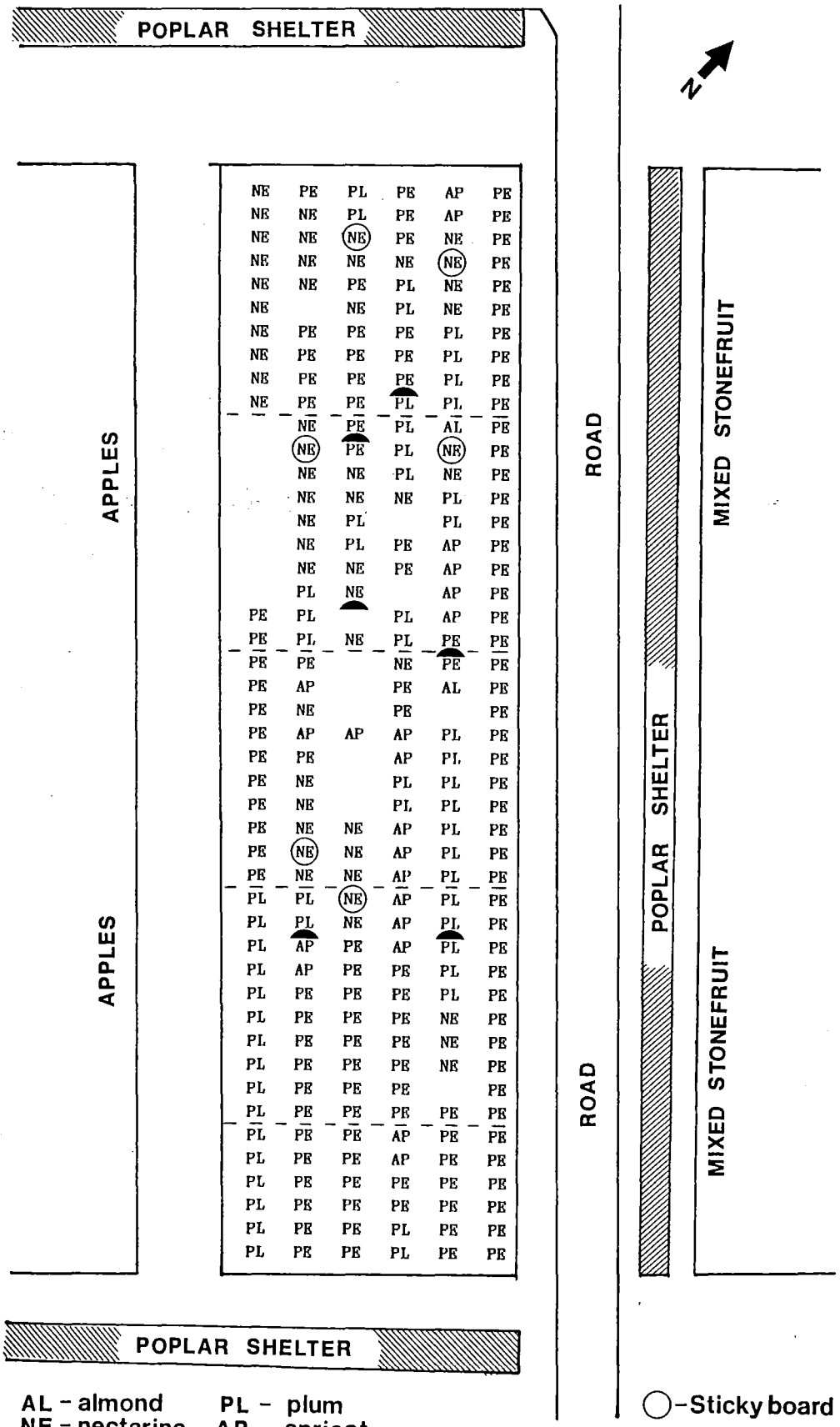
Block 1. Stonefruit. This block consisted of many varieties of newly-planted plums, apricots, peaches and nectarines. The trees were planted in 1979-80 and some varieties were removed and replaced during the course of of this work. The trees were grown on 0.5m ridges. Spacing of trees within and between rows was 4.5m x 5.5m. Shelter was provided by poplar (*Populus nigra* L). Herbicides were applied to ridges within tree rows to reduce vegetation. Strips of vegetation between the rows were mown regularly. Ground cover was dominated by various grasses, clover (*Trifolium repens* L.) and a number of weeds.

Block 2. Stonefruit. This block consisted of only peaches and nectarines which showed promise for stonefruit production in Canterbury. The trees were planted in 1980 and 1982. The trees were grown on 0.5m ridges. Spacing of trees within and between rows was 2 x 4.5m. Shelter was provided by poplar and macrocarpa (*Cupressus macrocarpa* Hartw.). Herbicides were applied to the ground cover to remove all vegetation.

Organic Area. This small block consisted of pip and stonefruit trees planted from 1984 onwards. Spacing of trees within and between rows was 1 x 2.5m. These trees recieved no pesticide applications. The ground cover and immediate surrounding area consisted of a great variety of flowering plants.

APPENDIX 5. continued

Orchard Map, Block 1



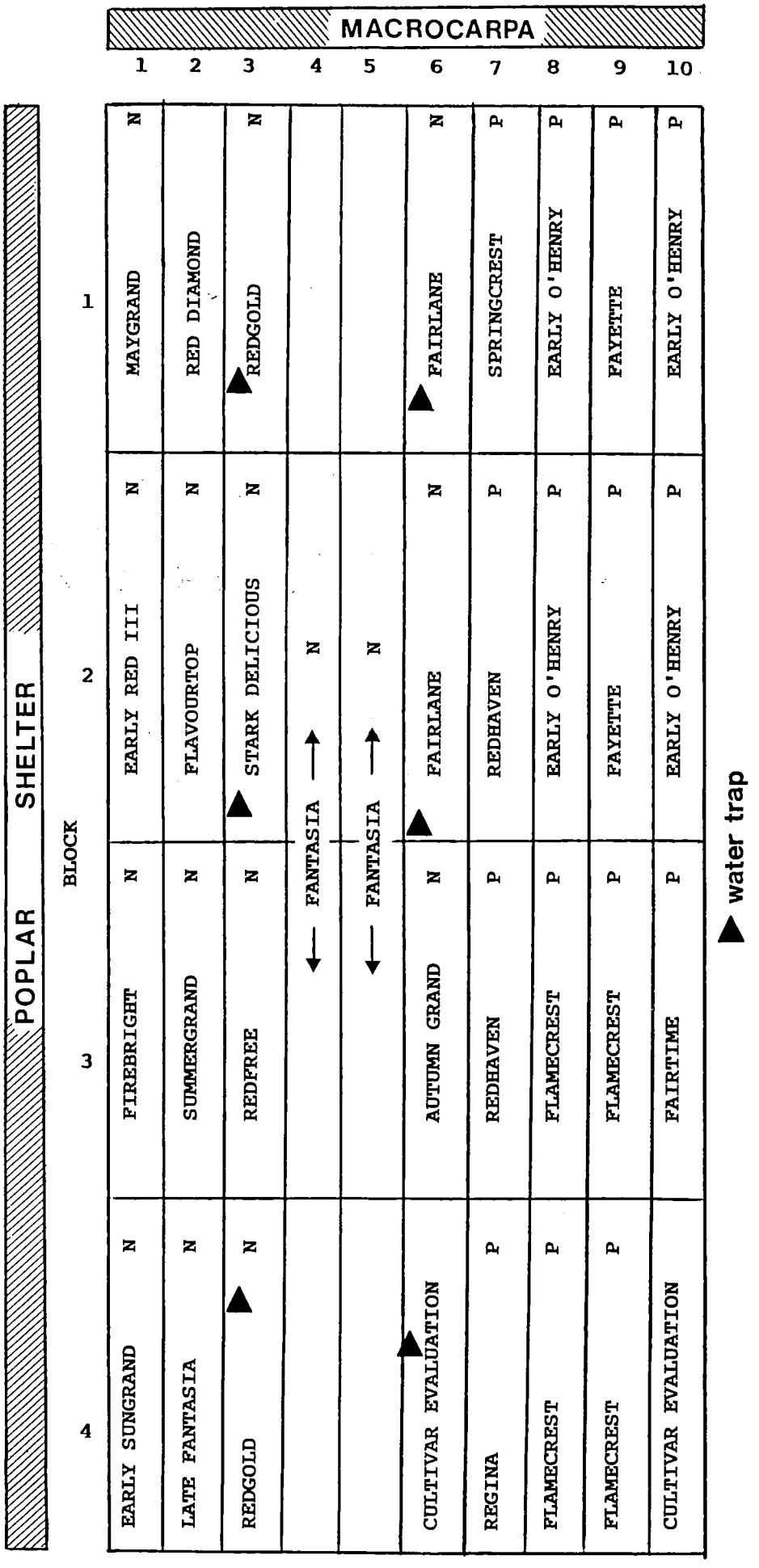
APPENDIX 5. continued.

Block 1. Varieties.

	ROW 6	ROW 5	ROW 4	ROW 3	ROW 2
1	Wilson's California				
2	Wilson's California				
3	Firebrite	Stark Delicious			Red Diamond
4	Firebrite	Red Gold	Independence	Harko	Red Diamond
5		Red Gold			Crimson Gold
6	Springred	Earliblaze			Crimson Gold
7	Flavourtop	Suncrest		Flamecrest	
8	Flavourtop	Suncrest		Flamecrest	
9					
10		Sun Gold?			
11		Le Grand			
12		Autumn Grand			Red Free
13		Autumn Grand	September Grand		Red Free
14		Regal Grand	September Grand	Armking	
15	Springold	Regal Grand			
16	Springold	Early Sungrand		Harbelle	
17	F/Gold	May Grand	Summer Grand	Harbelle	
18	F/Gold		Kent Grand		
19	Springold				
20	Springold		Hardired		Springcrest
21	Red April			Hardired	Springcrest
22	Red April	Fairlane		Fayette	
23	Springold			Fayette	
24					
25		Early Red I			
26		Early Red II	Red une		
27		Early Red III	Red June		
28	Royal May	Early Red III	Red June		
29	Royal May	Early Red III			
30			Royal Giant		
31			Royal Giant		
32					
33			Firered	Early O'Henry	
34		Golden Queen		Early O'Henry	
35			Golden Queen		Sunglow
36		Golden Queen			Sunglow
37			Golden Queen	Fairtime	Flavourtop?
38				Fairtime	
39		Redhaven	Redhaven		
40		Redhaven	Redhaven		
41		Redhaven	Redhaven		
42		Redhaven	Redhaven	Royal Red	Glow Haven
43		Redhaven	Redhaven		Dixiered
44		Redhaven	Redhaven		Dixiered
45		Redhaven	Redhaven		E/Glow

APPENDIX 5. continued

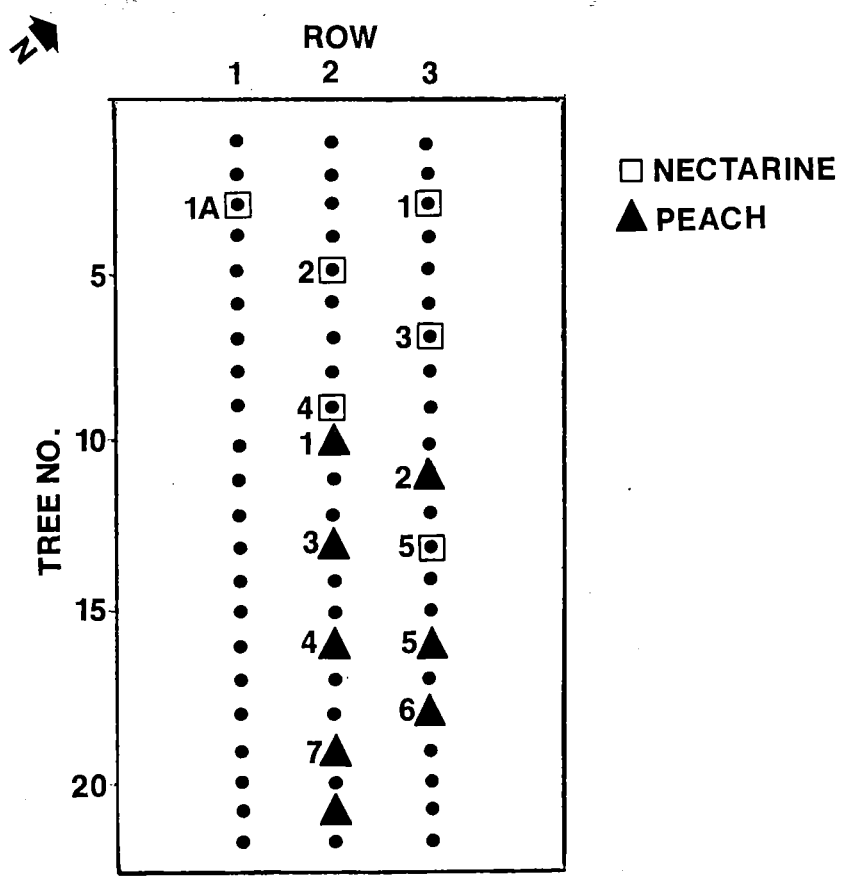
Orchard Map, Block 2



APPENDIX 5 continued.

Stonefruit Varieties Of The Organic Area, Lincoln College Horticultural Research Area.

	NECTARINE	SAMPLING PERIOD		PEACH	SAMPLING PERIOD
1	Early Red	10/9-14/9	1	Firered	10/9-3/11
1a	unknown	18/9-3/11	2	unknown	10/9-19/10
2	Harko	10/9-3/11	3	Parade	10/9-3/11
3	Wilson's California	10/9-3/11	4	Royal Gold	10/9-3/11
4	Spring Red	10/9-3/11	5	Royal May	10/9-3/11
5	Firebrite	10/9-28/9	6	Royal April	10/9-3/11
			7	unknown	10/9-3/11



APPENDIX 5. continued.

Block 1. Insecticide Applications, 1984-85.

DATE	CHEMICAL	PRODUCT	RATE PER 100l
18/8	lindane	Lindane	300g
5/10	azinphosmethyl	Gusathion	225g
2/11	azinphosmethyl	Gusathion	300g
22/11	primicarb	Pirimor	75g
6/12	carbaryl	Septan	300g
14/12	carbaryl	Septan	300g
2/1	dichlorvos	Vapona?	100ml
18/1	carbaryl	Septan	300g
25/1	dichlorvos	Vapona	115ml
13/2	carbaryl	Septan	300g
21/2	carbaryl	Septan	300g

Block 1. Insecticide Applications, 1985-86.

29/7	lindane & oil		
26/9	chlorpyrifos	Lorsban 50WP	50g
8/10	chlorpyrifos	Lorsban 50WP	
17/10	azinphosmethyl	Gusathion	
8/11	pirimicarb	Pirimor	
21/1	carbaryl	Septan	150g

Block 1. Insecticide Applications, 1986-87.

19/8	lindane & oil		100g
21/10	chlorpyrifos	Lorsban	75g
31/10	chlorpyrifos	Lorsban	75g
1/12	azinphosmethyl	Gusathion	75g
16/12	azinphosmethyl	Gusathion	75g
5/2	carbaryl	Septan	150g
17/2	carbaryl	Septan	150g

APPENDIX 5. continued.

Block 2. Insecticide Applications, 1985-86.

DATE	CHEMICAL	PRODUCT	RATE PER 100l
29/7	lindane & oil		
26/9	chlorpyrifos	Lorsban 50WP	50g
8/10	chlorpyrifos	Lorsban 50WP	
17/10	azinphosmethyl	Gusathion	
8/11	pirimicarb	Pirimor	
11/12	azinphosmethyl	Gusathion	75g
24/12	carbaryl	Septan 800	150g
6/1	carbaryl	Septan 800	150g
21/1	carbaryl	Septan 800	150g
28/1	carbaryl	Septan 800	
12/2	carbaryl	Septan 800	150g
3/3	carbaryl	Septan 800	150g

Block 2. Insecticide Applications, 1986-87.

19/8	lindane	Lindane 500	100g
21/10	chlorpyrifos	Lorsban 50WP	75g
31/10	chlorpyrifos	Lorsban 50WP	75g
5/12	azinphosmethyl	Gusathion C	75g
16/12	azinphosmethyl	Gusathion C	75g
27/12	carbaryl	Septan 800	150g
22/1	carbaryl	Septan 800	150g
17/2	carbaryl	Septan 800	150g
4/3	carbaryl	Septan 800	150g

APPENDIX 6. ADULT AND LARVAL HOSTS OF THE NEW ZEALAND FLOWER THRIPS.

KEY:

	* ENDEMIC TO NEW ZEALAND
POSITION (ON PLANT):	1 = FLOWER 2 = FRUIT 3 = LEAF 4 = PLANT 5 = SPEARS 6 = GROWING TIPS 7 = SHOOTS 8 = STEM 9 = TREE
MONTH (SAMPLE DATE):	i = JANUARY ii = FEBRUARY etc.
LOCATION:	Area codes from Crosby *et al.* 1976
STAGES:	F=FEMALE (>1) f=FEMALE (at least 1) M=MALE (>1) m=MALE (at least 1) L=LARVAE (>1) l=LARVAE (at least 1), all larvae reared to adult for I.D. For sex of larvae see Table 4.1
SOURCES:	MAFA = MAFQual Plant Protection Centre Lynfield, Auckland MAFC = MAFQual Plant Protection Centre Lincoln, Canterbury MAFL = MAFQual Plant Protection Centre Levin MAFW = MAFQual Head Office Wellington NZAC = New Zealand Arthropod Collection

		POSITION	MONTH	LOCATION	STAGES	SOURCE
PTERIDOPHYTA						
PTERIDACEAE						
**Pteridium esculentum*	bracken			MC		Winterbourn 1987
ANGIOSPERMAE-MONOCOTYLEDONS						
AGAVACEAE						
**Cordyline australis*	ti kauka/cabbage tree		xii	WN	F	NZAC
		1	xi	MC	F M L	new record
Doryanthes sp.		1				Spiller 1956
**Phormium cookianum*	wharariki/mountain flax	1	xi	CL	f	NZAC, Spiller 1956
**Phormium tenax*	harakeke/N.Z. flax			WN	f	Norton 1984
		1	xi	MC	F L	new record
Phormium sp.		1	i,xi	AK,WN	F M	Mound & Walker 1982, NZAC
AMARYLLIDACEAE						
Narcissus 2 sp.		1	vii	AK		MAFL
Nerine sp.		1	iv	WN		Carpenter 1987, MAFW
ARACEAE						
Zantedeschia aethiopica	arum lily	1	x-xii	AK,CL	F M	MAFA, NZAC
Zantedeschia sp.		1	i,xii	AK	F	MAFA
**Rhopalostylis sapida*	nikau	1	ii,xi,xii	NN,CL,SD	F M	NZAC, Spiller 1956

APPENDIX 6. continued.

CANNACEAE						
Canna x generalis	canna	1				Spiller 1956
IRIDACEAE						
Gladiolus sp.			ii	SL	f	NZAC
JUNCACEAE						
Juncus sp.	rushes		iii	SL	f	NZAC
LILIACEAE						
Asparagus officinalis	asparagus	1,5	iv	WO	F	MAFA, Watson 1983 Townsend & Watson 1984
**Bulbinella hookeri*	Maori onion	1,3	xii	NN	F M	Mound & Walker 1982, NZAC
Kniphofia sp.	red-hot poker		xi	WN	F m	NZAC
Lilium regale	christmas lily		xii	MC	f m	NZAC
ORCHIDACEAE						
	orchid		xi			MAFL
	outdoor orchid		vi	AK	F	MAFA
PANDANACEAE						
**Freycinetia banksii*	kiekie	1	xi	CL	f	NZAC, Spiller 1956
Freycinetia sp.		1	xi	CL	f	NZAC
POACEAE						
Agrostis stolonifera	creeping bent		iii	SL	f m	NZAC
Agrostis capillaris	brown top		iii	SL	f	NZAC
Ammophila arenaria	marram grass		ii	Chathams Is	f	NZAC
**Chionochloa rubra*	red tussock		ii	NN	F	NZAC
**Cortaderia toetoe*	toetoe		ii	MC	f	NZAC
Dactylis glomerata	cocksfoot		iii	SL	F	NZAC
Spartina sp.			iii	SL	F	NZAC
Zea mays	maize, corn		i,ii	AK,HB,GB,BP,WO	f	Cumber & Eyles 1960, NZAC

APPENDIX 6. continued.

ANGIOSPERMAE-DICOTYLEDONS						
ACTINIDIACEAE						
Actinidia deliciosa (=*A. chinensis*)	kiwifruit	1,2,3	x-xii	AK,BP,HB,NN,WO	F m	MAFA, MAFL, MAFW, Kirk 1987, Mound & Walker 1982, NZAC, Palmer-Jones & Clinch 1974, Spllier 1956
		1	xii	MC	F m	new record
ANNONACEAE						
Annona cherimola	cherimoya	3	v,vi	AK		MAFL
APIACEAE						
**Aciphylla aurea*		1	i	MK/SC	f m	NZAC
**Aciphylla glaucescens*	wild spaniard		xii	WN	F m	NZAC
**Anisotome aromatica*		1	xii	MC	F M L	new record
Conium maculatum	hemlock	2,3	i	Timsden		Spiller 1951,1956
Daucus carota	carrot	1	i,iii	BR,MK,SL	F M	NZAC
APOCYNACEAE						
Mandevilla laxa	Chilean jasmine	1	i,iii	MC	F M	new record
ARALIACEAE						
Fatsia sp.		1	iv	AK	F m	NZAC, Spiller 1951,1956
**Pseudopanax arboreus*	five finger	1		WN	F	Norton 1984
**Pseudopanax simplex*		2,3	iii	TK	f	NZAC, Spiller 1956
Pseudopanax sp.		1				MAFW
ASCLEPIADACEAE						
Dregia sinensis		1	i	MC	F M	new record

APPENDIX 6. continued.

ASTERACEAE						
Achillea millefolium	yarrow	1	iii	MC	F	new record
		1	v	MC	L	new record
**Cassinia* sp.		1	i	MC	F	new record
**Celmisia spectabilis*	(cotton plant)			MC,SC	f	NZAC
		1	ii	SC	F M 1	new record
**Celmisia viscosa*			ii	MC	f	Mound 1978, NZAC
Chrysanthemum macrophyllum		1	xii	MC	F M	new record
Chrysanthemum sp.		1	i,iii	AK,HB,MC,WN	F	MAFL, MAFC, NZAC
Cirsium arvense	Californian thistle	1	iii	SL	f m	NZAC
Cynara scolymus	globe artichoke		x	AK		MAFL
Dahlia sp.	dahlia	1	iii	SL	f	NZAC
		1	iii,iv	MC	F M	new record
		1	iv	MC	L	new record
**Helichrysum filicaule*		1	ii	SC	f	new record
Liatris sp.		1	ii		F	MAFA
Olearia sp.		1	xi	WD	F	NZAC
**Pachystegia insignis*		1	i	MC	F	new record
Senecio jacobaea	ragwort		iii	SL	f	NZAC
Tagetes erecta	marigold	1,3	iii-v	AK,SL	F m	NZAC, Spiller 1951,1956
Tanacetum vulgare	tansy	1	ii	AK,WN	f	NZAC
Taraxacum officinale	dandelion	1	xii	MC	F	new record
BERBERIDACEAE						
Berberis sp.			x	WN	f	NZAC
BIGNONIACEAE						
Catalpa bignonioides	Indian bean tree	1	i	MC	F M L	new record

APPENDIX 6. continued.

BRASSICACEAE						
Brassica hirta (=*Sinapis alba*)	mustard	1	viii	MC	L	new record
Brassica oleracea	brussels sprout	1	x	MC	F M l	new record
Brassica rapa	turnip		iii	RI		Cumber & Eyles 1960
Brassica sp.	chou moellier		ii	BP,HB,WO		Cumber & Eyles 1960
Cheiranthus cheiri	wallflower		xii	NN	F	NZAC
**Notothlaspi rosulatum*		1	i	BR	F m	NZAC
BRUNIACEAE						
Berzelia sp.		1				MAFW
BUDDLEJACEAE						
Buddleia davidii		1	ix	AK		Spiller 1951
		1	i	MC	F L	new record
Buddleia sp.		1	ix	HB		MAFL
CAMPANULACEAE						
**Wahlenbergia* sp.		1	xi	CO	F	new record
CALYCANTHACEAE						
Chimonanthus praecox	wintersweet	1	vii	MC	F	new record
CAPRIFOLIACEAE						
Lonicera japonica	Japanese honeysuckle	1	i	MC	F	new record
Sambucus nigra	elder	1	xii	MC	F M L	new record
Viburnum tinus	laurustinus	1	v,vii	MC	F L	new record
Viburnum sp.		1	viii,ix,x	MC	F M	new record
Weigela sp.		1	xi	WN	f	NZAC
CARYOPHYLLACEAE						
Dianthus caryophyllus	carnation	1,3	iii,xii	SL,WN	F	MAFL, NZAC
Gypsophila sp.		1	i			MAFL

APPENDIX 6. continued.

CHENOPODIACEAE						
Chenopodium quinoa	quinua	1	ii	MC	F	new record
CONVOLVULACEAE						
Calystegia sp.		1	x	ND	F m	NZAC
Convolvulus sp.		1	i	MC	F M	new record
Convolvulus sp.		1	xii	NN	F m	NZAC
CORNACEAE						
**Corokia x virigata*		1	xi	MC	f 1	new record
**Griselinia littoralis*	papauma/broadleaf	1		WN	f	Norton 1984
CORYLACEAE						
Corylus avellana	hazel		xi	WI	F	NZAC
CUCURBITACEAE						
Cucurbita sp.	buttemut squash	1	ii	AK	f	MAFA
CUNONIACEAE						
**Ackama rosaefolia*	makamaka		x	WN	f	NZAC
**Weinmannia racemosa*	kamahi	3	i	NN	m	NZAC
EPACRIDACEAE						
**Cyathodes fasciculata*	mingimingi		ii	ND	f	NZAC
**Dracophyllum subulatum*			x	TO	f	NZAC
Dracophyllum sp.		1	ii,xii	FD,SL	f m	NZAC
ERICACEAE						
Erica sp.		1	v	WN		MAFL
**Gaultheria rupestris*		1	xii	MC	F M L	new record
Rhododendron sp.	rhododendron	2,3	xi	TK		Spiller 1951,1956
Rhododendron sp.	azalea	1	x	WN	f	NZAC

APPENDIX 6. continued.

ESCALLONIACEAE						
Escallonia sp.		4	i	ND	F	MAFA, NZAC
FABACEAE						
**Carmichaelia grandiflora*		1		MK		Sweney 1980
**Carmichaelia odorata*		1	i	MC	L	new record
Cytisus scoparius	Scotch broom	3	iii	SL	F	NZAC
		1	iii,xi	MC	F M	new record
		1	i	MC	l	new record
Chamaecytisus palmensis	tree lucerne		xi	NN	F	NZAC
		1	viii-ix	MC	F	
		1	x	MC	L	new record
Erythrina sp.		1	iii	KA	f	NZAC
Glycine max	soybean		i	AK		MAFL
Lathyrus odoratus	sweet pea	1	xii	AK,NN	F	NZAC
		1	xii	MC	f	new record
Lupinus albus	white lupin		i	MC	f	MAFL, NZAC
Lupinus angustifolius	blue lupin		i	MC	F m	Harris 1980, NZAC
Lupinus arboreus	tree lupin		xii	ND	f	NZAC
Lupinus polyphyllus	Russell lupin	1	iii,xii	MC	F m	new record
		1	i	MC	L	new record
Lupinus sp.	lupin	1,3	ii,iii,x,xi	AK,SL,WI,WO	F m	NZAC
Medicago sativa	lucerne	1	ii,iii	MB,MC	F	MacFarlane & Pottinger 1976, NZAC
		4	xi	MC	F	new record
		1	i	MC	l	new record
Pisum sativum	garden pea	1	i	WN		MAFL
Robinia pseudoacacia	black locust	1	xii	MC	f	new record
		1	xi	MC	L	new record
**Sophora tetraptera*	kowhai	1	x	MC	F	
		1	xi	MC	L	new record
Spartium junceum	Spanish broom	1	i	MC	F M	new record

APPENDIX 6. continued.

Trifolium pratense	red clover	1,3	i,iii	BR,NN,SL,WN	F m	MAFL, NZAC
		1	i	MC	F M L	new record
Trifolium repens	white clover		i,xi	MB	F	NZAC
		1	i,xii	MC	F	new record
		1	i	MC	L	new record
Trifolium sp.	clover		xi	WI	f	NZAC
Ulex europaeus	gorse	1,3	i-iii,viii-xi	AK,BR,MC,NN,SL	F m	MacCarter & Gaynor 1980, NZAC
		1	viii,x,xii	MC	F M	new record
		1	iv,v,vii	MC	L	new record
Vicia faba	broad bean	1	i	WN		MAFL
		1	x	MC	F M L	new record
Wisteria sp.		1	xi	WN	f	NZAC
FAGACEAE						
Quercus sp.	oak	3	iii,xi	SL,WI	f	NZAC
**Nothofagus fusca*	tawhairaunui/red beech	3	i	NN	F M	NZAC
**Nothofagus menziesii*	tawhai/silver beech	3	i,iii	NN,SL	F M	NZAC
**Nothofagus solandri*			iii	SL	f	NZAC
Nothofagus sp.		3	i	NN	f	NZAC
GENTIANACEAE						
**Gentiana bellidifolia*			iii	SC	f	new record
**Gentiana corymbifera*			iii	NN	f	NZAC
		1	ii	MC	F M	new record
Gentiana sp.	gentian	1	iii	MK,NN	F M	NZAC, Mound 1978
HIPPOCASTANACEAE						
Aesculus hippocastanum	horse-chestnut		xi,xii	WN	f	NZAC
Aesculus indica	Indian horse-chesnut	1	xii	MC	F M L	new record
HYPERICACEAE						
Hypericum calycinum		1	xii	MC	f	new record
LAMIACEAE						
Lavandula sp.	lavender	1	xii	WN	F	NZAC
Origanum sp.	marjoram	1	i	MC	F M	new record
Rosmarinus officinalis	rosemary	1	x	MC	1	new record

APPENDIX 6. continued.

LAURACEAE						
**Beilschmiedia tawa*	tawa	1	x	WN	F	Norton 1984
Persea americana	avocado pear	1,2,3	xi,ix	BP,GB	F m	MAFA, MAFL
MAGNOLIACEAE						
Magnolia sp.					f	NZAC
MALVACEAE						
Alcea rosea	hollyhock		xi	WI	f	NZAC
Althaea officinalis	marsh mallow	1	i,ii	MC	F M l	new record
**Hoheria angustifolia*		1	i	MC	F m L	new record
**Hoheria lyalli*	(mountain ribbonwood)	1	ii	MC	F m	new record
**Hoheria sexstylosa*	(ribbonwood)			WN	f m	Norton 1984
		1	iii	MC	F L	new record
Malva moschata			ii	WN	f	NZAC
MIMOSACEAE						
Acacia baileyana	cootamundra wattle	1	viii	MC	f	new record
Acacia cultriformis	knife acacia	1	ix,x	MC	F M	new record
Acacia verticillata			xi	WN	f m	NZAC
Acacia sp.		1	ii,x	WN	f	MAFL, NZAC
Albizia distachya	plume albizzia	1	v	AK	F	NZAC, Spiller 1951,1956
MYOPORACEAE						
**Myoporum laetum*	ngaio	1		WN	F	Norton 1984

APPENDIX 6. continued.

MYRTACEAE						
Acca sellowiana (=*Feijoa sellowiana*)	feijoa	2,3,6	xi	AK		Spiller 1951, 1956
Agonis sp.		1				MAFL
Callistemon sp.	bottlebrush	3	v	MC	f	NZAC
**Kunzea ericoides*	kanuka/tea-tree	1	i	MC	F M L	new record
**Leptospermum scoparium*	manuka/tea-tree	2,3	ii,xi,xii	AK,ND,NN,WO	F m	NZAC, Spiller 1956
		1	i	MC	L	new record
Leptospermum sp.		1	x		F	MAFA, MAFW
**Metrosideros robusta*	rata		ii	WN	f	NZAC
Thryptomene sp.		1	viii	WO		MAFL, MAFW
ONAGRACEAE						
**Fuchsia excorticata*	kotukutuku	3	i,xi	NN,WN	F M	NZAC
Fuchsia x hybrida		1	i	MC	l	new record
Fuchsia sp.		1	xii	MC	F M	new record
OLEACEAE						
Ligustrum sp.	privet		i	MC	F M L	new record
Syringa sp.	lilac		x,xi	WN,WO	F m	NZAC
PAPAVERACEAE						
Papaver nudicaule	Iceland poppy		xi		F	NZAC
		1	vii,xi	MC	F M	new record
PAEONIACEAE						
Paeonia sp.	peony	1	x	NN	f m	NZAC
PASSIFLORACEAE						
Passiflora edulis	passionfruit	1,3,7	i-iii	BP,WN	F	MAFL, May 1963, NZAC

APPENDIX 6. continued.

PHILADELPHACEAE						
Deutzia sp.	deutzia	1	xii	MC	F m L	new record
Philadelphus sp.			xii	MC	F m	NZAC
PITTOSPORACEAE						
**Pittosporum eugenioides*	tarata/lemonwood		x	WN	F	NZAC
**Pittosporum tenuifolium*	kohuhu		iii	SL	f	NZAC
PLUMBAGINACEAE						
Limonium sinuatum	statice	1	i,ii	AK,HB		MAFL
		1	ii	MC	f	new record
POLYGONACEAE						
**Muehlenbeckia* sp.			xi	CL	F	NZAC
Polygonum persicaria			iii	SL	F	NZAC
Polygonum sp.	willow weed		iii	SL	f	NZAC
Rheum rhabarbarum	rhubarb		ii	AK		MAFL
		1	x	MC	F m	new record
PRIMULACEAE						
Cyclamen persicum	cyclamen	2,3	v	AK		Spiller 1951, 1956
PROTEACEAE						
Leucadendron sp.		3,8	vii,viii,xi	WO,AK,TK		MAFL, MAFW
Leucospermum sp.		1				MAFW
Macadamia sp.	Macadamia nut	1	ix,xi	ND	f	MAFA
Protea cynaroides	king protea	2,3	viii	AK	F	NZAC, Spiller 1956
Protea sp.		1	x	AK		MAFL, MAFW
Telopea sp.	waratah	1	ix,x	BP	F	MAFA
RANUNCULACEAE						
Anemone sp.		1	xi	WI	f	MAFW, NZAC
**Clematis hookeriana*				WN		Norton 1984
**Clematis paniculata*	puawhananga			WN		Norton 1984
Clematis vitalba	old man's beard		iii	NN,WN	F	NZAC
Clematis sp.			xi	WN	f	NZAC

APPENDIX 6. continued.

RHAMNACEAE						
Ceanothus sp.		1	vii,viii,ix	HB,WN	F M	MAFL
**Discaria toumatou*	matagouri		i	MK	f	NZAC
Phylica sp.		1	viii			MAFL, MAFW
Pomaderris sp.		2,3	ix		F	NZAC, Spiller 1956
ROSACEAE						
Crataegus x lavallei		1	xi	MC	l	new record
Cydonia oblonga	quince	1	x	MC	L	new record
Fragaria x ananassa	strawberry	2				MAFW
Fragaria chiloensis		2				MAFW
Fragaria vesca			i	AK		MAFL
Fragaria sp.	strawberry	2,4	xi,xii	AK,WN	f	MAFA, MAFL, MAFW, Mound & Walker 1982
Malus pumila		1	x	WN		MAFL
Malus sylvestris	apple	1	x,xi	HB,WN	F	NZAC, Spiller 1956
		1	x,xi	MC	F	new record
		1	x	MC	L	new record
Prunus armeniaca	apricot	1,2				MAFW, McLaren unpubl.
		2	i	MC	F M	new record
		2	i	MC	L	new record
Prunus domestica	plum	1	ix,x	AK,WI	f M	MAFA, MAFL, NZAC, Spiller 1951
Prunus lusitanica	Portugal laurel	1	xii	MC	F m	new record
Prunus persica	peach	2,3,9	i-iii,xi,xii	AK,CO,GB,HB, MC,NN,WN	F	MAFA, McLaren 1986, NZAC, Spiller 1951,1956
		1,2	i-iii,ix,x,xii	MC	F M	new record
		1	x	MC	L	new record
		2	i,iv	MC	L	new record
Prunus persica		1,2	i,ix	HB,WN	?	MAFL
Prunus persica var. *nectarina*	nectarine	1,2,3,4,9	i,ii,ix,x,xi	CO,WI,WN	F M	MAFL, McLaren 1981,1984,1985,1986, McLaren unpubl., NZAC
		1,2	ii,iii,ix-xi	MC	F M	new record
		1	x	MC	L	new record
Prunus serrulata	Japanese flowering cherry	1	ix	WI		MAFL
Prunus yedoensis	Yoshino cherry	1	ix,x	MC	F	new record
		1	x	MC	L	new record
Prunus sp.	sour cherry	1	x	CO		McLaren 1984
Prunus sp.	cherry		xi	WI	f	NZAC
Prunus sp.		3	iii	SL	f	NZAC

APPENDIX 6. continued.

Pyrus communis	pear	1	x	MC	F L	new record
Rosa sp.	sweet briar		i	MK	f	NZAC
Rosa sp.	rose	1	ii-iv,xi,xii	AK,CO,DN,GB, HB,MC,NN,SL,WN	F M	MAFL, NZAC, McLaren 1985, Spiller 1956
		1	i,iii,v	MC	F	new record
		1	iii,iv	MC	L	new record
Rubus fruticosus	blackberry	1,2	i,ii	SL,WO	f m	MAFL, NZAC
		1	i	MC	f m L	new record
Rubus idaeus	red raspberry	2	i,x-xii	NN,WO	F m	MAFA, MAFC, MAFL, NZAC
Rubus phoenicolasius	Japanese wineberry		ii	BP	F	MAFA
Rubus ursinus	boysenberry	2,3	i,x	AK,CO	f	NZAC, Spiller 1956
Rubus ursinus	youngberry	1	xi	CO	f	NZAC, Spiller 1956
Rubus ursinus	loganberry		xii	WO		MAFL
Rubus sp.	bush lawyer		x	WN	f	NZAC
Rubus sp.		2	xii	WO		MAFL,MAFW
RUBIACEAE						
**Coprosma foetidissima*		3	i	SD	f m	NZAC
**Coprosma robusta*	karamu	3	i	SD	F M	NZAC
Coprosma sp.			xii	FD	f	NZAC
Luculia gratissima		1	iii	SL	f M	NZAC
RUTACEAE						
Boronia megastigma		1,8	x	BP		MAFL
Boronia sp.		1	x	BP	F	MAFA
Choisya ternata	Mexican orange	1	iii	MC	F M	new record
		1	xi	MC	L	new record
Citrus limon	lemon	1,2,3,9	ii,x-xii	AK,BP,GB,NN	F	NZAC, Spiller 1951,1956
Citrus paradisi	goldfruit, grapefruit	1,2,3	x-xii	AK	F	NZAC, Spiller 1951,1956
Citrus sp.	orange		xi	BP	F	NZAC
Citrus sp.	tangelo	1		BP,GB,ND		Gerson 1983
Citrus sp.		1	ii,x,xii	AK,BP,GB,HB,SD	F m	NZAC, Vardy 1987
SALICACEAE						
Salix matsudana		1	ix,x	MC	F	new record
Salix sp.		1	ix	MC	F	new record

APPENDIX 6. continued.

SAPINDACEAE						
**Alectryon excelsus*	titoki		xi	WI	f	NZAC
SAXIFRAGACEAE						
Astilbe x arendsii		1	xii	MC	F M L	new record
Ribes rubrum	red currant	2	i			MAFL
Ribes sp.		2				MAFW
SCROPHULARIACEAE						
**Hebe elliptica*			ii	SI	f	NZAC
**Hebe parviflora*		1	ii	MB	F	NZAC
**Hebe speciosa*		1		WN	F	Norton 1984
		1	i	MC	F M L	new record
**Hebe stricta*		1	i	TK	f M	NZAC
**Hebe vernicosa*		1	xii	MC	F M L	new record
**Hebe venustula*			vii	BR	F	NZAC
?*Hebe* sp.		1	i,ii	MK,NN,WN	F m	Mound & Walker 1982, NZAC
Verbascum thapsus	woolly mullein	1	iii,v-viii,xii	NN,CO	F	NZAC, McLaren 1985
SOLANACEAE						
Nicotiana tabacum	tobacco	1,2,3	xi	NN	F M	NZAC, Spiller 1951,1956
Solanum tuberosum	potato	1,2,3	iii,xi	TK,WI	M	MAFL, NZAC, Spiller 1956
STYRACACEAE						
Pterostyrax hispidus		1	xii	MC	F M L	new record
THYMELAEACEAE						
Daphne sp.		1	vii	WN	F	MAFL
TILIACEAE						
**Aristotelia serrata*	makomako/wineberry		x	SD	F	NZAC
**Elaeocarpus dentatus*	hinau	1	xi	WN	f	Norton 1984, NZAC
VACCINIACEAE						
Vaccinium sp.		2	i	AK		MAFL,MAFW

APPENDIX 6. continued.

VERBENACEAE						
Lantana sp.		1	xii	HB		MAFL
**Vitex lucens*	puriri	1,2,3	viii	AK	f M	NZAC, Spiller 1956
VIOLACEAE						
**Melicytus ramiflorus*	mahoe/whitey-wood	1	xii	WN	f m	Norton 1984
VITACEAE						
Vitis vinifera	grape	1	xii	AK	F	NZAC, Crawford 1941
WINTERACEAE						
**Pseudowintera axillaris*	horopito	1		WN	f m	Norton 1984
**Pseudowintera colorata*	horopito/(pepper tree)			WN	f	Norton 1984
**Pseudowintera traversii*				NN	f	Norton 1984?
OTHER						
	bird's nest		xi	AK	f	Mound & Walker 1982, NZAC
	kelp (under in sand)		ii	Chatham Is	f	NZAC
	leaf mould		x,xii	BP,SD	F m	NZAC
	lichen (on manuka)		i	NN	f	NZAC
	litter		i-iv	BR,CL,CO,FD, GB,NN,ND,OL, RI,SI,SD,TK, Three Kings Is	F m	Mound 1978, NZAC
	marsh		i	CL	f	NZAC
	moss		i-iii,vi,xii	MB,NN,WO,WN, Chatham Is	f M	Mound 1978, NZAC
	pasture		i-iv,vi,ix-xii	AK,NN,WO	F m	MAFA, NZAC
	sward		i-iii,xii	CO,FD,NN,TK	F m	Mound 1978, NZAC
	turf		xi	NN	F m	NZAC

APPENDIX 7. THRIPS SPECIES CAUGHT IN WATER TRAPS, ORGANIC AREA, LINCOLN COLLEGE HORTICULTURAL RESEARCH AREA, SPRING 1987.

	Trap no.						Trap no.						Trap no.						Trap no.					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
SPECIES	10/9/87						17/9/87						24/9/87						1/10/87					
Chirothrrips manicatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Limothrips cerealium	1	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	2	1	1	2
Thrips obscuratus F	1	4	1	7	2	3	6	6	5	10	2	4	3	2	2	0	1	1	3	1	2	1	2	1
Thrips obscuratus M	0	0	0	1	0	1	1	0	1	4	0	1	0	0	1	1	0	0	1	0	0	0	2	0
Thrips tabaci	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	15/10/87						22/10/87																	
Chirothrips manicatus	0	0	1	0	0	0	1	0	0	0	0	0												
Limothrips cerealium	1	0	1	1	1	1	0	0	0	0	0	0												
Thrips obscuratus F	0	1	0	2	0	2	13	5	8	7	4	2												
Thrips obscuratus M	1	3	2	2	0	0	7	4	5	9	0	6												
Thrips tabaci	1	0	2	0	0	0	4	0	1	0	1	0												

APPENDIX 8. CONSTITUTED STICKY SUBSTANCE FOR STICKY TRAPS.

The sticky compound for traps was made in the following way:

Ingredients:

1. 55.5% Polybutene
2. 34.5% 5300 Resin (Exxon Cemical Co.)
3. 3.8% Microcrystalline wax
4. AC 400 wax (Eastman Co. U.S.A.)

Method:

1. Heat the polybutene
2. Melt the resin and waxes
3. Stir all together

The resin is largely responsible for the field properties and general stickiness. The quantity of resin may be changed according to conditions.

To apply the sticky compound a solvent is used to make it more viscous. Petroleum ether or white spirits are suitable solvents.

APPENDIX 9. THRIPS SPECIES CAUGHT IN WATER TRAPS, BLOCK 1, LINCOLN COLLEGE HORTICULTURAL RESEARCH AREA, WINTER 1985.

	Trap no.						Trap no.						Trap no.						Trap no.					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
SPECIES			4/4/85						11/4/85						18/4/85						26/4/85			
Haplothrips niger	0	0	0	0	1	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Ceratothrips frici	2	5	0	2	0	1	0	3	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0
Thrips australis	1	0	0	2	0	0	0	1	1	0	0	0	0	2	0	1	1	3	5	5	6	6	3	3
Thrips obscuratus F	0	1	0	1	3	0	1	0	2	1	1	3	0	0	0	0	0	3	0	3	2	2	3	6
Thrips obscuratus M	1	0	1	0	0	0	0	0	0	0	2	2	1	0	0	0	1	0	0	0	1	1	1	0
Thrips tabaci	0	1	0	0	1	0	3	0	1	2	2	3	0	2	3	0	1	1	5	2	3	3	2	9
Other	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	2	1	0	0	0	1	0	0
			2/5/85						9/5/85						16/5/85						24/5/85			
Haplothrips niger	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ceratothrips frici	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0		0	0	0	0	0	0
Thrips australis	0	0	2	1	1	0	0	1	2	0	1	1	1	0	0	0	0	1	2	0	0	2	2	0
Thrips obscuratus F	0	0	0	0	0	1	1	1	1	0	2	1	1	0	1	0	1	2	0	1	1	0	0	1
Thrips obscuratus M	0	0	0	0	0	0	1	0	3	2	0	2	0	0	0	0	1	0	0	0	1	1	0	3
Thrips tabaci	3	1	2	3	0	1	4	3	6	4	1	6	6	2	3	3	2	1	0	0	0	0	0	0
			30/5/85						6/6/85						13/6/85						20/6/85			
Ceratothrips frici	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Thrips australis	0	0	0	0	0	0	0	0	0	0	1	0	2	0	0	0	0	1	1	0	0	0	0	1
Thrips obscuratus F	0	0	1	0	0	0	0	0	1	0	1	0	0	0	2	1	2	0	1	0	0	0	0	0
Thrips obscuratus M	0	0	0	0	0	0	1	0	0	0	0	0	0	0	3	1	0	0	0	0	0	0	0	0
Thrips tabaci	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			5/7/85						12/7/85															
Thrips australis	0	0	0	0	1	0	0	1	0	1	0	1												
Thrips obscuratus F	0	1	3	1	3	0	0	0	0	0	0	0												
Thrips obscuratus M	1	0	0	0	1	0	0	0	0	0	0	0												

APPENDIX 10. THRIPS SPECIES CAUGHT IN WATER TRAPS, BLOCK 1, LINCOLN COLLEGE HORTICULTURAL RESEARCH AREA, SUMMER 1985-86.

	Trap no.						Trap no.						Trap no.						Trap no.					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
SPECIES			28/8/85						4/9/85						11/9/85						18/9/85			
Limothrips cerealium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0
Thrips obscuratus F	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
			25/9/85						3/10/85						10/10/85						17/10/85			
Limothrips cerealium	3	2	3	2	1	3	1	2	4	1	3	0	0	0	0	0	0	0	0	0	0	0	0	1
Thrips australis	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Thrips obscuratus F	1	0	1	0	4	4	1	1	2	1	2	1	1	1	0	0	0	1	0	0	0	0	0	0
Thrips obscuratus M	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0
Thrips tabaci	0	0	0	0	0	0	0	0	1	0	0	0	0	1	2	0	1	1	0	0	0	0	0	0
			24/10/85						31/10/85						7/11/85						14/11/85			
Haplothrips niger	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	1	0	1	2
Chirothrips manicatus	1	0	0	1	1	2	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Limothrips cerealium	1	0	0	0	2	0	1	0	1	0	0	0	1	1	0	0	0	0	0	0	1	0	0	0
Ceratothrips frici	0	1	0	0	0	0	0	1	0	0	0	0	1	1	0	0	0	0	1	1	1	2	0	1
Thrips australis	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Thrips obscuratus F	0	1	1	2	1	3	1	0	2	5	2	3	1	4	2	4	5	4	4	1	1	2	1	3
Thrips obscuratus M	0	1	0	0	0	0	0	0	0	0	0	2	2	2	0	1	0	0	0	0	0	1	2	0
Thrips tabaci	0	4	2	2	2	2	2	1	1	1	2	4	1	2	2	4	1	0	1	3	1	0	2	2

APPENDIX 10. continued.

	Trap no.						Trap no.						Trap no.						Trap no.					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
SPECIES			21/11/85						28/11/85						5/12/85						11/12/85			
Haplothrips niger	2	1	0	0	0	0	0	0	2	1	1	1	1	3	1	3	14	4	2	2	7	3	9	0
Aeolothrips fasciatus	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Limothrips cerealium	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	4	2	2	0	0	1
Ceratothrips frici	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Thrips australis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Thrips obscuratus F	0	1	1	1	4	2	0	0	1	3	3	2	1	0	2	2	0	7	5	2	4	7	7	12
Thrips obscuratus M	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	1	3	0
Thrips tabaci	4	3	1	1	0	1	0	0	2	0	3	3	0	4	3	3	14	6	3	3	3	1	5	4
Thrips vulgatissimus	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Other	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
			17/12/85						26/12/85						3/1/86						9/1/86			
Haplothrips niger	2	5	0	0	2	1	2	1	0	0	1	3	1	1	0	0	0	1	1	1	0	0	1	0
Aeolothrips fasciatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Chirothrips manicatus	0	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0
Limothrips cerealium	0	5	3	3	4	3	9	14	18	14	25	6	14	14	20	22	5	2	13	8	16	1	10	9
Frankliniella occidentalis	0	1	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	1	0	0	1	0	0
Thrips australis	2	2	0	0	0	0	0	0	0	0	1	1	0	0	0	0	1	0	0	0	0	0	0	0
Thrips obscuratus F	7	8	12	15	22	18	9	6	19	33	23	23	5	6	14	44	12	23	10	6	20	22	13	22
Thrips obscuratus M	1	0	0	0	2	1	0	2	1	0	5	2	1	1	2	3	4	1	1	0	2	3	3	1
Thrips tabaci	16	7	10	16	22	8	11	20	13	12	57	22	13	14	8	3	10	4	53	71	68	29	89	52
Thrips vulgatissimus	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2	0	0	1
Other	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2	1	1	0	1	1	1

APPENDIX 10. continued.

	Trap no.						Trap no.						Trap no.						Trap no.					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
SPECIES			16/1/86*						23/1/86*						5/2/86*						21/2/86			
Aeolothrips fasciatus	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Limothrips manicatus	10	6	23	5	7	5	8	8	5	2	9	0	2	0	3	1	5	3	5	0	0	3	0	3
Anaphothrips obscurus	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ceratothrips frici	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	3	0	3
Frankliniella occidentalis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Thrips obscuratus F	4	6	8	12	14	7	15	13	26	17	38	35	1	4	3	3	4	19	4	6	17	37	44	59
Thrips obscuratus M	0	0	3	0	2	3	0	1	0	1	5	1	0	0	0	0	1	0	0	0	0	2	0	1
Thrips tabaci	29	29	28	16	54	35	50	85	56	31	68	41	26	43	15	21	20	16	44	28	30	14	14	26
Thrips vulgatissimus	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other	0	0	2	0	0	0	1	1	1	0	2	0	0	1	0	0	1	0	0	2	1	0	0	1
			7/3/86						21/3/86						3/4/86						17/4/86			
Halpothrips niger	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Aeolothrips fasciatus	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ceratothrips frici	0	1	0	3	2	1	4	3	5	5	5	3	0	0	1	0	0	1	0	0	0	1	1	0
Frankliniella occidentalis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
Thrips obscuratus F	0	1	0	13	7	11	4	2	5	11	9	19	0	0	1	2	0	0	2	1	3	1	4	4
Thrips obscuratus M	0	0	0	0	0	2	2	1	5	2	7	5	0	0	0	0	0	1	0	1	0	0	0	1
Thrips tabaci	3	2	11	2	7	9	18	23	13	2	12	5	0	3	1	0	0	0	1	1	5	1	0	0
Other	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0

* 25% SUBSAMPLE

APPENDIX 11. THRIPS SPECIES CAUGHT IN WATER TRAPS, BLOCK 2, LINCOLN COLLEGE HORTICULTURAL RESEARCH AREA, SUMMER 1985-86.

	Trap no.						Trap no.						Trap no.						Trap no.					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
SPECIES			28/8/85						4/9/85						11/9/85						18/9/85			
Thrips obscuratus F	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
			25/9/85						3/10/85						10/10/85						17/10/85			
Limothrips cerealium	8	3	1	7	3	14	3	6	9	5	5	18	1	2	1	3	0	2	2	0	1	0	0	1
Chirothrips manicatus	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Anaphothrips obscurus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Thrips australis	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Thrips obscuratus F	0	2	0	1	0	0	0	1	0	0	0	0	1	0	0	1	0	0	1	1	0	1	0	0
Thrips obscuratus M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0
Thrips tabaci	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
			24/10/85						31/10/85						7/11/85						14/11/85			
Haplothrips niger	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	2	0	5	0	1
Chirothrips manicatus	0	0	0	0	0	2	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0
Limothrips cerealium	3	1	0	1	0	0	0	1	0	0	0	1	2	2	3	0	1	1	0	0	0	0	0	0
Anaphothrips obscurus	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ceratothrips frici	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	1	0	1	0	1
Frankliniella occidentalis	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Thrips australis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Thrips obscuratus F	0	6	0	1	2	1	0	3	1	1	0	0	3	11	1	6	0	0	0	0	0	3	1	1
Thrips obscuratus M	0	5	0	3	0	0	0	0	0	0	0	0	0	2	0	2	1	0	1	1	0	0	0	0
Thrips tabaci	4	3	0	2	3	4	1	0	0	1	2	1	3	5	5	6	4	2	0	2	0	5	2	1
Other	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0

APPENDIX 11. continued.

	Trap no.						Trap no.						Trap no.						Trap no.					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
SPECIES			21/11/85						28/11/85						5/12/85						11/12/85			
Haplothrips niger	3	1	2	0	2	3	0	1	1	1	0	4	10	9	14	9	19	8	20	14	21	15	21	12
Limothrips cerealium	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	2	0	0	3	6	4	5	2	2
Anaphothrips obscurus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Ceratothrips frici	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Thrips australis	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Thrips obscuratus F	1	1	1	1	1	1	2	3	2	3	0	1	2	6	1	3	1	5	8	14	2	13	5	2
Thrips obscuratus M	0	0	0	2	0	0	1	1	0	2	0	1	0	0	0	0	1	0	0	2	2	2	0	1
Thrips tabaci	6	0	1	4	5	1	2	3	2	2	2	3	8	6	9	10	8	5	10	7	11	10	7	7
Thrips vulgatissimus	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Others	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	1	1	0	0	1
			17/12/85						26/12/85						3/1/86						9/1/86			
Haplothrips niger	8	10	8	4	11	6	8	3	2	0	4	1	1	2	-	3	4	2	0	0	2	1	3	2
Aeolothrips fasciatus	0	0	0	0	0	0	0	0	0	0	1	0	0	1	-	0	0	1	0	0	0	0	0	0
Chirothrips manicatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	0	0	1	0	1	0	1	0	0
Limothrips cerealium	1	6	1	7	3	4	17	22	8	25	19	19	18	17	-	35	8	16	12	13	10	21	4	14
Anaphothrips obscurus	0	0	0	0	0	0	0	0	0	0	0	0	0	1	-	0	0	0	1	0	1	0	0	1
Frankliniella occidentalis	0	1	0	0	0	0	0	0	0	0	0	0	1	0	-	0	1	0	1	1	0	1	0	1
Thrips australis	0	1	0	0	0	0	0	3	0	2	1	0	0	4	-	1	0	1	0	1	1	0	0	1
Thrips obscuratus F	11	25	8	8	4	2	39	48	19	21	7	7	33	67	-	28	16	5	32	94	21	27	16	4
Thrips obscuratus M	0	4	0	0	0	0	4	6	4	1	1	2	3	7	-	2	1	1	0	4	2	5	4	3
Thrips tabaci	25	16	15	36	11	12	18	27	19	26	15	22	17	15	-	37	9	8	77	71	78	134	89	90
Thrips vulgatissimus	0	0	0	0	0	0	1	1	0	0	0	1	1	0	-	0	0	0	0	0	1	0	2	0
Others	0	0	0	0	0	0	0	0	0	0	0	0	0	1	-	1	0	0	0	0	0	3	1	1

APPENDIX 11. continued.

	Trap no.						Trap no.						Trap no.						Trap no.					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
SPECIES			16/1/86*						23/1/86*						5/2/86*						21/2/86			
Haplothrips niger	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Aeolothrips fasciatus	0	0	0	0	0	0	0	1	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0
Limothrips manicatus	5	7	6	28	3	19	5	2	5	8	0	5	2	0	1	5	2	3	0	0	0	0	1	0
Anaphothrips obscurus	0	0	0	0	0	0	0	0	1	0	1	1	1	0	1	0	1	0	0	0	1	0	0	0
Ceratothrips frici	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	3	1	2
Thrips australis	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	3	0	0
Thrips obscuratus F	17	23	9	16	6	0	61	91	25	23	14	3	6	15	4	4	6	2	23	47	11	22	9	3
Thrips obscuratus M	6	2	0	2	1	0	3	5	5	3	1	0	0	4	0	0	0	0	1	3	0	1	0	0
Thrips tabaci	32	24	43	63	44	39	45	64	58	95	43	48	6	58	10	42	11	10	1	31	4	49	3	11
Thrips vulgatissimus	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other	0	1	1	0	0	0	0	0	1	0	1	0	0	1	0	0	0	2	0	1	0	0	0	0
			7/3/86						21/3/86						3/4/86						17/4/86			
Haplothrips niger	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Anaphothrips obscurus	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ceratothrips frici	2	2	1	0	3	2	3	9	7	14	13	4	0	0	0	0	1	1	0	0	0	1	1	1
Frankliniella occidentalis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Thrips australis	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Thrips obscuratus F	7	16	14	4	10	2	18	15	16	13	27	5	15	16	8	3	7	1	3	4	7	4	4	4
Thrips obscuratus M	0	1	0	0	0	1	3	3	6	10	6	0	0	0	1	4	0	0	0	3	1	3	0	1
Thrips tabaci	2	3	2	3	2	3	3	9	4	14	1	9	0	0	0	3	0	1	0	1	1	0	0	2
Other	0	0	1	0	1	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0

* 25% SUBSAMPLE

APPENDIX 12. THRIPS SPECIES CAUGHT IN WATER TRAPS, BLOCK 2, LINCOLN COLLEGE HORTICULTURAL RESEARCH AREA, WINTER 1986.

	Trap no.						Trap no.						Trap no.						Trap no.					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
SPECIES			2/5/86						16/5/86						30/5/86						12/6/86			
Haplothrips niger	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ceratothrips frici	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Thrips australis	0	0	1	0	1	0	0	2	3	2	0	1	0	0	0	3	1	0	2	0	1	0	1	0
Thrips obscuratus F	1	2	4	6	7	5	1	1	0	1	4	3	2	0	2	1	2	1	1	0	0	2	3	1
Thrips obscuratus M	1	2	1	1	2	0	0	2	0	0	4	2	0	0	0	0	1	0	0	0	0	0	0	0
Thrips tabaci	2	1	0	0	1	3	10	5	7	1	3	7	0	0	0	0	0	0	0	0	0	0	0	0
Other	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0
			27/6/86						25/7/86						22/8/86									
Thrips australis	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0						
Thrips obscuratus F	0	1	0	0	0	0	0	0	0	0	1	0	1	3	0	0	1	2						
Thrips obscuratus M	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0						
Thrips tabaci	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0						

APPENDIX 13. THRIPS SPECIES CAUGHT IN WATER TRAPS, BLOCK 2, LINCOLN COLLEGE HORTICULTURAL RESEARCH AREA, SUMMER 1986-87.

	Trap no.						Trap no.						Trap no.						Trap no.					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
SPECIES			4/9/86						12/9/86						18/986						2/10/86			
Limothrips cerealium	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	5	6	1	5	0	4
Thrips obscuratus F	0	0	0	0	1	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Thrips obscuratus M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0
			9/10/86						16/10/86						23/10/86						29/10/86			
Chirothrips manicatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Limothrips cerealium	1	0	1	1	1	0	1	0	0	0	0	0	6	7	0	10	2	5	0	2	1	0	0	1
Thrips australis	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Thrips obscuratus F	1	1	0	1	0	0	0	2	0	1	0	0	2	4	2	4	4	1	4	10	6	18	0	4
Thrips obscuratus M	0	2	0	0	0	0	0	1	0	0	0	0	0	5	1	2	1	0	0	6	1	2	0	0
Thrips tabaci	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	1	0	7	5	2	0	1
			5/11/86						12/11/86						27/11/86						11/12/86			
Haplothrips niger	1	0	0	0	0	0	1	2	2	1	1	1	4	6	15	6	9	13	12	37	49	31	15	12
Aeolothrips fasciatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Desmidothrips walkerae	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Limothrips cerealium	1	1	0	1	1	1	2	2	0	0	0	0	0	0	0	0	0	1	3	2	0	3	1	1
Anaphothrips obscurus	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0
Ceratothrips frici	0	0	0	0	0	0	4	4	4	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0
Frankliniella occidentalis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Thrips australis	0	1	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Thrips obscuratus F	1	24	4	14	1	3	4	33	9	18	4	4	20	19	9	23	14	9	14	9	30	13	4	2
Thrips obscuratus M	0	1	2	3	0	0	1	6	1	1	1	1	5	5	3	2	2	2	0	2	0	1	0	0
Thrips tabaci	3	1	2	3	0	2	0	7	7	7	1	5	1	0	4	0	0	0	1	2	3	1	0	3
Thrips vulgatissimus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0

APPENDIX 13. continued.

	Trap no.						Trap no.						Trap no.						Trap no.					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
SPECIES			24/12/86						7/1/87						21/1/87*						5/2/87*			
Haplothrips niger	0	2	1	2	0	3	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Aeolothrips fasciatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Chirothrips manicatus	2	5	6	3	1	2	0	0	0	0	2	2	0	1	2	1	0	0	0	1	0	0	0	0
Limothrips cerealium	20	31	8	37	8	17	3	7	1	3	5	4	5	3	0	4	1	2	0	0	0	0	1	1
Anaphothrips obscurus	0	0	1	1	0	0	3	1	0	1	0	2	0	0	0	3	1	0	3	1	0	5	2	1
Ceratothrips frici	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
Frankliniella occidentalis	0	0	1	2	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	1	0
Thrips australis	1	0	2	2	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Thrips obscuratus F	16	72	27	41	11	17	34	105	44	39	52	22	85	65	124	38	84	41	17	22	44	33	55	37
Thrips obscuratus M	2	4	2	7	1	4	0	2	2	0	3	0	4	3	3	2	5	8	1	0	5	0	0	1
Thrips tabaci	2	11	7	17	1	11	3	4	6	0	1	4	18	5	13	8	4	17	34	25	58	32	12	39
Thrips vulgatissimus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Other	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0
			18/2/87						4/3/87						18/3/87						2/4/87			
Aeolothrips fasciatus	1	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Limothrips cerealium	1	0	0	0	0	-	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Ceratothrips frici	0	0	2	1	3	-	0	1	0	1	1	1	1	0	0	0	0	10	1	0	1	2	0	0
Frankliniella occidentalis	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Thrips australis	0	0	0	0	0	-	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Thrips obscuratus F	28	9	65	23	15	-	40	22	54	34	58	29	4	8	11	20	39	8	0	4	7	8	1	8
Thrips obscuratus M	3	1	4	1	0	-	2	0	0	2	1	4	1	1	1	0	2	4	0	1	0	2	0	0
Thrips tabaci	7	1	3	3	1	-	1	3	1	9	1	3	0	3	0	2	0	2	1	13	0	1	0	1
			15/4/87																					
Ceratothrips frici	1	0	0	0	1	2																		
Thrips obscuratus F	8	2	8	1	5	3																		
Thrips obscuratus M	1	0	0	1	0	1																		
Thrips tabaci	0	0	1	1	1	3																		

* 25% SUBSAMPLE

APPENDIX 14. THRIPS SPECIES CAUGHT IN WATER TRAPS, BLOCK 2, LINCOLN COLLEGE HORTICULTURAL RESEARCH AREA, WINTER 1987.

	Trap no.						Trap no.						Trap no.						Trap no.					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
SPECIES			4/5/87						20/5/87						3/6/87						18/6/87			
Thrips australis	0	0	0	0	2	0	0	4	0	4	2	4	1	0	0	0	0	0	0	0	0	0	0	0
Thrips obscuratus F	1	2	5	3	0	1	1	1	2	3	1	1	0	1	0	0	0	3	0	0	0	0	0	0
Thrips obscuratus M	0	0	0	0	0	1	3	2	0	3	0	7	0	0	0	0	0	1	0	0	0	0	0	0
Thrips tabaci	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0						
			6/7/87						24/7/87						11/8/87						28/8/87			
Thrips obscuratus F	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	2	0	0
Thrips obscuratus M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Frankliniella occidentalis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0

APPENDIX 15. THRIPS SPECIES CAUGHT IN WATER TRAPS OUTSIDE ORCHARD BLOCKS, LINCOLN COLLEGE HORTICULTURAL RESEARCH AREA, 1985-1987

	Trap no.						Trap no.						Trap no.						Trap no.					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
SPECIES			10/10/85						14/11/85						11/12/85						23/1/86*			
Haplothrips niger	0	0	0	0	0	-	0	0	0	0	0	0	3	0	9	4	8	5	0	0	0	0	-	-
Aeolothrips fasciatus	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	-	-
Chirothrips manicatus	0	0	0	1	0	-	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	-	-
Limothrips cerealium	1	0	2	2	0	-	0	0	0	0	0	0	3	1	1	0	4	6	2	5	1	2	-	-
Anaphothrips obscurus	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	0	-	-
Ceratothrips frici	0	0	0	0	0	-	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	-	-
Thrips obscuratus F	2	0	2	0	1	-	0	1	0	0	0	1	1	0	1	5	4	2	15	63	6	12	-	-
Thrips obscuratus M	0	0	0	0	0	-	2	0	0	0	0	0	1	1	0	0	0	0	18	38	0	3	-	-
Thrips tabaci	1	1	0	1	3	-	0	0	0	0	1	1	1	6	5	1	9	13	104	208	133	163	-	-
Other	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	-	-
			21/2/86						21/3/86#						17/4/86						18/9/86			
Haplothrips niger	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	3	0	0	0	0	0	0	0	0
Aeolothrips fasciatus	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Limothrips cerealium	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Anaphothrips obscurus	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ceratothrips frici	0	0	0	0	0	0	0	1	0	2	0	0	1	1	1	1	1	0	0	0	0	0	0	0
Franklíniella occidentalis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0
Thrips australis	0	1	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0
Thrips obscuratus F	5	28	1	7	3	1	1	2	11	12	7	4	3	13	5	0	4	1	0	1	0	0	0	0
Thrips obscuratus M	3	1	1	2	0	0	3	11	17	5	11	5	1	3	3	1	0	2	0	0	0	0	0	0
Thrips tabaci	30	73	42	43	20	35	14	17	50	28	24	28	2	0	6	8	1	14	0	0	0	0	0	0
Other	0	0	0	0	0	0	0	0	0	1	0	0	0	0	2	0	0	0	0	0	0	0	0	0

* 10% SUBSAMPLE

\# 25% SUBSAMPLE

APPENDIX 15. continued.

	Trap no.						Trap no.						Trap no.						Trap no.					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
SPECIES			16/10/86						12/11/86						11/12/86						7/1/87			
Haplothrips niger	-	0	0	0	0	-	2	0	2	12	1	1	24	9	19	25	21	19	0	-	1	0	1	0
Aeolothrips fasciatus	-	0	0	0	0	-	0	0	1	0	0	0	0	0	0	0	0	0	0	-	0	0	0	0
Limothrips cerealium	-	1	1	0	0	-	1	2	0	3	1	0	2	4	6	4	1	3	1	-	1	2	1	6
Anaphothrips obscurus	-	0	0	0	0	-	1	0	0	3	1	1	0	0	1	0	0	0	1	-	0	2	0	0
Ceratothrips frici	-	0	0	0	0	-	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Thrips australis	-	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	1	0	-	0	0	0	0
Thrips obscuratus F	-	1	0	2	2	-	0	41	6	46	0	8	3	8	17	48	13	54	11	-	20	51	5	4
Thrips obscuratus M	-	0	0	1	0	-	5	17	4	17	2	4	3	0	1	7	4	6	2	-	2	4	0	0
Thrips tabaci	-	0	0	1	0	-	46	55	36	204	34	85	27	29	17	53	20	39	14	-	13	29	3	4
Other	-	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	-	0	0	0	0
			12/2/87[#]						4/3/87						2/4/87						4/5/87			
Haplothrips niger	0	3	0	0	1	0	1	0	2	2	0	4	0	0	0	0	0	0	0	0	0	0	0	0
Aeolothrips fasciatus	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Limothrips cerealium	0	2	1	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0
Anaphothrips obscurus	0	0	0	2	0	2	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Ceratothrips frici	0	0	0	1	0	0	0	0	0	1	0	0	1	2	0	1	0	0	1	0	0	0	0	0
Frankliniella occidentalis	1	0	0	0	0	0	1	0	0	0	0	1	0	0	0	2	0	0	0	0	0	0	0	0
Thrips australis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0
Thrips obscuratus F	5	1	9	8	9	9	25	27	11	17	8	23	10	26	9	21	4	23	5	6	1	1	1	0
Thrips obscuratus M	1	0	1	1	1	1	4	12	2	10	2	3	3	4	0	0	0	2	3	3	0	2	0	2
Thrips tabaci	160	147	120	178	67	65	22	20	50	59	25	54	3	3	6	10	3	6	0	0	1	0	0	1
			3/6/87						6/7/87						11/8/87									
Frankliniella occidentalis	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0						
Thrips australis	0	0	1	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0						
Thrips obscuratus F	11	10	1	6	2	3	0	1	0	0	0	0	2	0	1	3	0	0						
Thrips obscuratus M	6	1	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0						
Thrips tabaci	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0						

[#] 25% SUBSAMPLE

APPENDIX 16. THRIPS SPECIES CAUGHT IN ATTRACTION EXPERIMENTS.

SPRING, COLOUR. 23/9/85-30/9/85.

	Trap no.					Trap no.					Trap no.				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
SPECIES		WHITE					YELLOW					RED			
Chirothrips manicatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Limothrips cerealium	1	2	3	2	5	3	2	3	2	0	3	4	2	3	2
Ceratothrips frici	1	0	0	0	1	0	1	0	1	0	0	0	0	0	0
Thrips obscuratus F	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0
Thrips tabaci	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0
		GREEN					BLUE					BLACK			
Chirothrips manicatus	1	0	0	0	3	0	0	0	0	1	0	0	0	0	1
Limothrips cerealium	1	2	2	4	3	0	3	1	2	3	1	3	0	3	0
Thrips obscuratus F	0	0	0	2	0	0	0	0	0	0	1	0	0	0	0

SPRING, SCENT. 16/9/85-20/9/85.

		CONTROL					ANISALDEHYDE					ETHYL NICOTINATE			
Tubilifera	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Limothrips cerealium	1	2	1	4	0	0	0	1	1	0	1	1	0	0	0
Ceratothrips frici	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Thrips obscuratus F	0	1	0	1	2	4	4	4	10	3	42	44	31	114	64
Thrips obscuratus M	0	0	0	0	0	4	3	2	8	1	46	57	29	214	99
		PEACH JUICE					BENZALDEHYDE								
Tubilifera	0	1	0	0	0	0	0	0	0	0					
Limothrips cerealium	1	0	2	1	3	1	1	0	0	2					
Ceratothrips frici	0	1	0	1	0	0	0	0	0	0					
Thrips obscuratus F	1	1	0	1	0	2	2	3	2	0					
Thrips obscuratus M	0	0	0	0	0	0	0	1	2	1					

APPENDIX 16. continued.

SUMMER, COLOUR. 16/1/86-20/1/86.

	Trap no.					Trap no.					Trap no.				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
SPECIES		WHITE					YELLOW					RED			
Tubilifera	1	0	1	0	0	2	0	0	0	0	0	0	0	1	0
Aeolothrips fasciatus	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
Chirothrips manicatus	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Limothrips cerealium	7	4	7	7	5	8	6	6	6	1	4	6	6	4	5
Anaphothrips obscurus	0	0	1	0	0	1	0	0	1	0	0	0	0	0	0
Ceratothrips frici	0	0	1	0	0	10	6	14	3	3	0	0	0	0	0
Frankliniella occidentalis	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Thrips obscuratus F	2	4	17	2	4	3	3	2	1	2	0	0	1	0	0
Thrips obscuratus M	1	4	16	1	6	0	3	0	3	0	0	0	1	0	0
Thrips tabaci	99	194	153	71	57	293	197	173	318	90	1	4	1	1	0
Thrips vulgatissimus	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
			GREEN					BLUE					BLACK		
Tubilifera	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0
Aeolothrips fasciatus	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Chirothrips manicatus	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Limothrips cerealium	6	15	6	1	7	10	7	6	2	2	9	8	2	7	5
Anaphothrips obscurus	1	1	2	0	0	0	0	0	0	0	0	0	0	1	0
Ceratothrips frici	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Frankliniella occidentalis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Thrips obscuratus F	1	0	0	0	3	0	0	5	1	1	1	3	0	1	0
Thrips obscuratus M	0	0	0	0	1	0	1	0	2	0	1	0	0	0	1
Thrips tabaci	16	14	7	4	8	16	17	6	8	6	1	4	0	2	3
Thrips vulgatissimus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

APPENDIX 16. continued.

SUMMER, SCENT. 10/2/86-11/2/86.

	Trap no.					Trap no.					Trap no.				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
SPECIES		CONTROL					ANISALDEHYDE					ETHYL NICOTINATE			
Tubilifera	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0
Aeolothrips fasciatus	0	0	0	0	0	0	1	1	0	0	0	1	1	0	0
Chirothrips manicatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Limothrips cerealium	0	0	0	0	2	0	1	2	0	0	0	0	0	0	0
Anaphothrips obscurus	1	1	0	4	4	1	0	3	2	0	0	1	0	0	0
Ceratothrips frici	0	1	0	0	1	0	0	0	0	0	1	1	1	0	0
Frankliniella occidentalis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Thrips obscuratus F	0	0	0	2	3	3	2	60	12	92	28	72	124	55	427
Thrips obscuratus M	0	0	0	1	0	0	3	17	6	5	7	12	24	7	62
Thrips tabaci	32	31	34	10	5	342	330	185	254	65	76	190	147	130	39
Other	1	1	0	1	0	2	0	2	0	0	0	0	0	0	0
		PEACH JUICE					BENZALDEHYDE					PEACH FRUIT			
Tubilifera	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
Aeolothrips fasciatus	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Chirothrips manicatus	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Limothrips cerealium	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0
Anaphothrips obscurus	1	0	0	1	1	0	1	0	0	0	0	0	0	1	0
Ceratothrips frici	0	0	0	0	1	0	0	0	0	0	0	0	1	0	1
Frankliniella occidentalis	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Thrips obscuratus F	0	0	0	0	6	2	10	4	34	125	2	0	1	1	5
Thrips obscuratus M	0	0	0	0	0	0	3	1	1	5	0	0	0	0	0
Thrips tabaci	43	13	36	17	2	279	273	503	227	18	22	32	10	6	6
Other	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0

APPENDIX 17. GRADE STANDARDS FOR EXPORT STONEFRUIT

Extract from *New Zealand Gazette*, Thursday, 29 November 1984, No. 223, page 5377

Standard Grade for the Export of Nectarines and Peaches (Notice No. 3396; Ag. 12/2/14)

THIS notice revokes the Standard Grade for the Export of Nectarines and Peaches Notice 1977 (No. 1629; Ag. 12/2/14), published in the *New Zealand Gazette*, Thursday, 3 February 1977.

PURSUANT to the New Zealand Grown Fruit and Vegetables Regulations 1975*, the Director-General of Agriculture and Fisheries hereby gives notice that the Standard Grade for the Export of Nectarines and Peaches shall be set out in this notice.

NOTICE

1. Title—(1) This notice may be cited as the Standard Grade for the Export of Nectarines and Peaches Notice 1984.

(2) This notice shall come into force on the day after the date of its notification in the *New Zealand Gazette*.

2. Interpretation—Unless the context otherwise requires, terms and expressions used in this notice shall have the same meaning as in the New Zealand Grown Fruit and Vegetables Regulations 1975*. Certain of these terms and expressions as applicable to fruit are defined in the First Schedule to this notice.

3. Application of Notice—This notice determines the standard grade for the export of nectarines and peaches from New Zealand.

4. Title and Grade—The grade mark assigned to this standard grade shall be 'Fancy' (hereinafter referred to as 'the grade').

NOTE—Consignments to European markets may have to meet specific OECD grade requirements. Refer to Second Schedule for further information.

5. Definition of Produce—This grade applies to nectarines and peaches grown from varieties of *Prunus persica* (L) Batsch to be supplied fresh to the consumer.

6. Provisions Concerning Quality—The purpose of this standard is to define the quality requirements for nectarines and peaches at the dispatching stage, after preparation and packaging.

(a) The nectarines and peaches must be,

—free from pests and diseases and meet any quarantine and other legal requirements of the importing country.
—intact, whole fruit.
—sound.
—clean.
—reasonably well formed—typical of variety and not more than slightly misshapen.
—free from abnormal external moisture; and
—free of foreign smell or taste.

(b) The nectarines and peaches must have been carefully picked and of a similar degree of maturity and colouring in the same line of produce. They must have matured sufficiently to complete the ripening process and be able to withstand handling, storage and transport to meet the market requirements at the place of destination.

(c) The nectarines and peaches must be of good quality and have characteristics typical of the particular variety and be free of defects which—

(i) May significantly impair the general appearance or keeping quality of the fruit; or

(ii) Are likely to make the fruit unattractive to the purchaser.

(d) The flesh must be sound, but each nectarine or peach is permitted a slight defect of shape, development or colouring and skin defects of a superficial nature such as light russet and that caused by limb or leaf rub and hail provided on size counts—

(i) 28 and larger, the aggregate area of one or more defects does not exceed 1 square centimetre, and defects of an elongated nature do not exceed 2 centimetres in length.

(ii) 30 and smaller, the aggregate area of one or more defects does not exceed 0.5 square centimetres and defects of an elongated nature do not exceed 1 centimetre in length.

(e) Colouring Criteria—for coloured strains the surface area of each fruit is required to display blushed or red colouration to the minimum percentage as follows:

Nectarine 30 percent Peach 20 percent

7. Provisions Concerning Sizing—Sizing is determined by the maximum diameter of the equatorial section. The minimum size allowed for export is:

Nectarines 55 mm diameter
Peaches 55 mm diameter

The difference in diameter of nectarines or peaches in the same package shall not exceed 5 mm.

8. Provisions Concerning Presentation—

(a) Uniformity

The contents of each package must be uniform; each package must contain only nectarines or peaches of the same origin, variety, quality, degree of ripeness and size.

The visible part of each package must be representative of the entire contents.

(b) Packaging

The nectarines or peaches must be packed in such a way as to ensure that they are suitably protected.

The materials, and particularly the paper used inside the package, must be new, clean and of a quality such as to avoid causing any external or internal damage to the produce. The use of materials and particularly of paper or stamps bearing trade specifications is allowed provided that the printing or labelling has been done with a non-toxic ink or glue.

Packages must be free of all foreign matter.

9. Provisions Concerning Marking—Each package must bear the following particulars in letters grouped on the same side, legibly and indelibly marked and visible from the outside:

—Identification—registered mark of grower or packing establishment and exporter's identification;
—Nature of produce—kind and variety;
—Country of origin—New Zealand;
—Packing date code—registering the date of packing;
—Commercial Specification—grade, count or size.

Labels, if used must not be less than 40 square centimetres.

FIRST SCHEDULE

DEFINITION OF TERMS

'Clean' means free from dirt, dust, insect stains or other foreign substance or material;

'Count' means the number of fruit contained in any package;

'Mature', in relation to fruit, means that the fruit will properly complete the ripening process and is suitable for export;

'To pack' means to arrange fruit regularly and compactly in a package so that they are not loose or compressed to an extent likely to cause damage to the fruit during handling or transport;

'Sound' means free from decay, rots, overmaturity, breakdown, freezing injury, damage and similar defects which may cause rapid loss of condition or rapid decay;

'Storage defects' means decay, storage scald, fungal rots, wilt, or other injury to fruit as a result of storage.

SECOND SCHEDULE

GRADE REQUIREMENTS FOR EUROPEAN MARKETS

1. Some European countries are members of the OEDC Scheme for the International Standardisation of Fruit and Vegetables and as such NZMAF is required to supply an OECD Control Certificate stating that the produce conforms to the OECD schemes grade standards.

2. Before exporting nectarines or peaches to a European country, exporters should check with a Regional Ministry of Agriculture and Fisheries office to ascertain if the importing country requires a control certificate, and obtain a copy of the OECD grade standards.

Notwithstanding clause 2 of this Schedule it is the responsibility of the exporter to ensure that produce exported meets the legal requirements of the importing country and the specifications of the importer.

THIRD SCHEDULE

GENERAL INFORMATION

1. In order to certify produce fit for export a certifying officer may require information from the exporter to the effect that the property on which the fruit was produced has been registered for export. It is the responsibility of the exporter to obtain this information from the Executive Officer of the N.Z. Stonefruit Export Council.

2. To assist with the interpretation of 'sound' fruit that has not been exported within 18 days of harvest will be considered unsound.

3. Growers and Exporters must ensure that fruit is kept under optimum storage conditions between harvest and dispatch.

Dated at Wellington this 22nd day of November 1984.

M. L. CAMERON,
Director-General of Agriculture and Fisheries.

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P. D. Hasselberg, Government Printer, Wellington, New Zealand—1984

APPENDIX 17. continued.

New Zealand Summerfruit (formally Stonefruit) Council Regulation's for Russet Only.

		maximum aggregate allowance	
		Elongated	Block
1984/85	Counts 28 and larger	2 cm x 0.3 cm	1.0 sq cm
	Counts 30 and smaller	1 cm x 0.3 cm	0.5 sq cm
1986/87	Counts 28 and larger	3 cm x 0.3 cm	1.5 sq cm
	Counts 30 and smaller	1 cm x 0.3 cm	0.5 sq cm

APPENDIX 18. THE LINCOLN SPRINGS ORCHARD.

Location: Latitude 43° 36′ S, latitude 172° 30′ E

Height above sea level: 20m.

The orchard is separated from other orhards by at least one kilometer and is surrounded on two sides by mixed cropping and by pasture on the other two. The property consists of 28 hectares, 12 one hectare blocks were planted with stonefruit in the winter of 1985. A 'Lombardy poplar shelter with a inner shelter of *Eucalyptis fraxiniodes* was around the perimeter but the blocks were seperated by 'Matsudana' willows (after Cruikshank 1987).

Insecticide Applications.

DATE	CHEMICAL	PRODUCT	RATE PER 100l
19/8	lindane	Lindane	100g
13/10	chlorpyrifos	Lorsban	50g
4/11	chlorpyrifos	Lorsban	50g
6/11	primicarb	Pirimor	
5/12	azinphosmethyl	Gusathion	75g
18/12	azinphosmethyl	Gusathion	75g
10/1	diazinon	Diazonon	100g
	carbaryl	Septan	100g
	carbaryl	Septan	100g

APPENDIX 19. THRIPS SPECIES CAUGHT IN WATER TRAPS BAITED WITH ETHYL NICOTINATE, LINCOLN SPRINGS ORCHARD, SPRING, 1986

	Trap no.						Trap no.						Trap no.						Trap no.					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
SPECIES			2/10/86						9/10/86						17/10/86						23/10/86			
Limothrips cerealium	8	3	3	3	6	2	2	3	0	1	2	1	6	8	4	6	4	4	2	3	4	2	2	0
Thrips australis	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	1	0	1
Thrips obscuratus F	0	0	2	0	1	3	1	0	2	0	0	1	5	5	8	7	2	12	18	25	58	15	9	35
Thrips obscuratus M	0	0	3	0	0	1	0	0	2	0	0	0	0	2	2	1	0	0	3	1	10	2	0	4
Thrips tabaci	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	5	2	6	2	1	5
Thrips vulgatissimus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
			29/10/86																					
Limothrips cerealium	1	2	1	3	3	2																		
Thrips australis	0	0	1	0	0	2																		
Thrips obscuratus F	54	30	59	15	12	34																		
Thrips obscuratus M	10	3	7	2	0	5																		
Thrips tabaci	2	1	1	0	2	4																		
Other	1	0	0	0	0	0																		

ADDENDUM

A RE-EXAMINATION OF THE PEST MANAGEMENT STRATEGIES FOR THE NEW ZEALAND FLOWER THRIPS

D.A.J. TEULON

INTRODUCTION

The New Zealand flower thrips is an important stonefruit pest at flowering and harvest in New Zealand. In the past, control strategies have been developed in the absence of a good ecological data base. This thesis has considerably extended the biological and ecological understanding of the New Zealand flower thrips, and in the light of this work the management of this pest should be re-examined.

An understanding of ecological concepts is useful in developing efficient pest management procedures (Price and Waldbauer 1982). The concept of r/K selection proposed by MacArthur and Wilson (1967) and expanded by Pianka (1970) is useful to pest managers in several ways. It provides general insights to the ecology of pest species and may help to identify the tactics best suited for the management of a pest exhibiting a particular r/K strategy (Southwood 1977, Stenseth 1981).

R/K STRATEGISTS

The concept of r/K selection developed from the theory of 'island biogeography' (MacArthur and Wilson 1967) and emphasises the different behaviour of species or populations inhabiting different environments. r-selected species or populations inhabit variable and/or unpredictable environments where mortality is often related to density-independent factors (e.g. weather). Population density is therefore variable and is often below the carrying capacity of the habitat. The r-strategist is an excellent colonist and can quickly exploit new habitats as it has good powers of dispersal and high fecundity. In unstable habitats rapid development enhances survival. Conversely, K-selected species or populations inhabit fairly constant and/or predictable habitats where mortality is often related to density-dependent factors (e.g. competition). Population density is more constant, at or near the carrying capacity of the habitat. K-selected individuals invest in increased survivorship rather than maximising reproduction.

Like all generalisations, the r/K dichotomy is an over-simplification and has been criticised for moving away from the original concept relating to island colonisation. Nevertheless it has been found to be a useful distinction, and has provided an important conceptual framework for many ecological studies (Begon *et al.* 1986).

The New Zealand flower thrips exhibits the opportunist behaviour of an extreme r-strategist, rapidly colonising new habitats. Originally an inhabitant of native flowers, the thrips has colonised many introduced flowers as well as the fruit of stonefruit. High fecundity and short generation time ensure that the small, highly mobile adults can fully exploit their ephemeral flower habitats. Population density varies

enormously and appears to be largely regulated by climatic factors. There is little evidence of effective regulation by natural enemies. The New Zealand flower thrips has many similarities to the polyphagous flower thrips *Thrips imaginis*, from which the concept of population regulation by density-independent factors was developed (Andrewartha and Birch 1954).

PEST MANAGEMENT

Agricultural crops superficially resemble 'ecological islands' in both a spatial and temporal sense. Many crops are isolated from similar habitats, and the beginning of a new cropping cycle provides a new area for immediate colonisation. Sometimes management practices (e.g. harvest, insecticide applications) prevent the development of a stable environment, so that new opportunities are continually provided for colonisation by insect pests. In these environments the ability of r-strategists to quickly colonise and establish large populations makes them particularly important pests. Compared with many crops deciduous fruit orchards (including pip and stonefruit) are more permanent ecosystems and provide for a wide range of r- and K- strategists (see Table 1).

TABLE 1. CLASSIFICATION OF SELECTED NEW ZEALAND DECIDUOUS TREE FRUIT PESTS RELATIVE TO R/K-STRATEGIES.

SPECIES	REPRO-DUCTION	SURVIVOR-SHIP	DISPERSAL	HABITAT
codling moth	K	K	K	K
Oriental fruit moth	K	K	K	K
leafrollers	K	K	r	r
scales	r	r	K	r/K*
mites	r	r	K	r/K*
leafhoppers	K	r	r	K
aphids	r	r	r	r/K*
thrips	r	r	r	r

* different species exhibit different preferences

In New Zealand orchards almost all 'key' pests (e.g. codling moth, Oriental fruit moth, leafrollers) are either K-strategists or exhibit many K-strategy traits. Population fluctuations of these pests are relatively minor but the factors that regulate them are unable to keep populations below acceptable levels. As they often attack the fruit directly and cause significant economic loss, the development of orchard pest

management strategies has been primarily concerned with these pests. Insecticides currently provide the main tactic for control but possibilities exist in the use of novel techniques such as sterile males and pheromone confusion (see Table 2).

Intermediate r/K strategists are generally 'occasional' (e.g. leafhoppers) or 'secondary' (e.g. mites, scales) pests. Most of these pests tend toward r-selection but they may have limited generations per year (e.g. leafhoppers) or limited powers of dispersal (e.g. mites, scales). For many of these pests the use of pesticides has led to pest resurgence and problems with resistance. For intermediate r/K strategists biological control is seen as an important method for control (see Table 2).

There are few true r-strategists in deciduous orchards in New Zealand. Aphid species are generally considered r-strategists but the woolly apple aphid is specifically adapted to the stable orchard environment and has only limited times for dispersal. It is well controlled in unsprayed orchards by a parasite and thus displays certain K characteristics. The green peach aphid and thrips are the only insect pests that exhibit true r-strategies.

TABLE 2. THEORETICAL OPTIMAL PEST CONTROL STRATEGIES FOR R/K STRATEGISTS (AFTER SOUTHWOOD 1977).

r-strategists	minimise immigration
	pesticides
	host resistance
intermediate	biological control
K-strategists	modify habitat
	reproductive control
	pesticides

The New Zealand flower thrips is a unique pest of New Zealand deciduous tree fruit crops in being an r-strategist and also a significant direct pest of stonefruit at both flowering and harvest. This thrips' ability to quickly colonise orchards in large numbers from hosts plants outside the orchard poses specific problems for pest management. Management practices which are restricted to within the orchard will have little influence on the thrips population density. Other direct pests are concentrated within the orchard and are more accessible for management.

Control methods for true r-strategists are largely restricted to minimising immigration, plant resistance and the use of insecticides (see Table 2). Some methods that are effective for K and intermediate r/K strategists are not suitable for r-strategists (e.g. pheromone confusion and biological control).

For pest management of the New Zealand flower thrips on stonefruit at flowering, immigration may be restricted by the removal of the few nearby breeding host plants and appropriately timed cultivation, but it is unlikely that this will sufficiently reduce thrips numbers to prevent economic damage. Plant varieties that show resistance to thrips attack have not been identified and development of new varieties is very slow. In the past the use of pesticides on flowers has been restricted because of the danger to bees. The incorporation of pesticides with low toxicity to bees into spray programmes at flowering has been a significant development in thrips control. Control of the other r-strategist infesting stonefruit flowers, the green peach aphid, can be facilitated by the use of oils to kill overwintering eggs while the tree is still dormant and before there is any danger to bees.

The control of thrips at harvest is a more intractable problem. In the forseeable future the use of pesticides will remain the main tactic for the control of key pests, as export fruit needs to be largely free from pest damage and contamination. As some K-strategists (and some r/K intermediates) have predictable population fluctuations with few generations, pesticide use can be reduced by targeting applications to susceptible times in the pests' life cycles. With r-strategists, overlapping and short generation times make this impossible.

Pesticide residues on fruit need to be low for market acceptance. With direct pests that are K-strategists, pesticide applications can be stopped some time before harvest (usually about 2 weeks) because there is little chance of a large population increase through reproduction or immigration. Conversely, the New Zealand flower thrips needs continual pesticide coverage because of the large numbers entering from outside the orchard. The problem of pesticide residues is exacerbated by the increasing attraction of thrips to peaches as they mature and the short storage life of peaches. To reduce the residue levels on fruit, pesticides with a short residual life have been used for thrips control. However, these soon lose their effectiveness in the field and reinfestation occurs. The use of pesticides with long residual activity at low concentrations may provide a useful alternative for reducing thrips numbers, but is unlikely to eliminate them completely.

Since the New Zealand flower thrips is a direct pest at harvest as well as an r-strategist, the alternative control strategies normally appropriate to r-strategists are inadequate to deal with the problem. Developing plant resistance in deciduous crops requires a commitment to long-term research (see above) and does not offer short- or mid-term solutions for pest management. Limiting immigration and reproduction through the removal of host plants would be impractical in summer as there are too many host plants outside the orchard. Selection of stonefruit varieties that ripen after January reduces thrips infestation of fruit (but not below economic threshold levels) in Canterbury by avoiding the periods of peak thrips flight. The use of baited (ethyl nicotinate) traps surrounding the orchard is a possible method for reducing immigration but needs considerable research. This approach may actually increase pest density by attracting thrips from further away.

SUMMARY

In contast to most direct pests of deciduous tree fruit crops which exhibit K-strategies, the New Zealand flower thrips is strongly r-selected. This poses new challenges for pest management, because the development of control strategies in deciduous tree fruit crops has been based on of 'key' pests exhibiting K-strategies. Control of the New Zealand flower thrips is particularly difficult at harvest. At this time the control methods developed and proposed for K and intermediate r/K strategists are not suitable for this r-strategist. Furthermore, accepted control methods for r-strategists are not suitable for a direct pest of deciduous fruit. Therefore new technologies such as those developed for postharvest disinfestation will play an important role in future control.

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