

LIFE HISTORY AND POPULATION DYNAMICS OF WESTERN FLOWER THRIPS,  
*FRANKLINIELLA OCCIDENTALIS* (PERGANDE) (THYSANOPTERA:THRIPIDAE) IN  
NECTARINE ORCHARDS IN THE DRY CENTRAL INTERIOR, BRITISH COLUMBIA

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## ABSTRACT

Nectarine production in the Dry Central Interior, British Columbia, has recently grown in status from a minor specialty crop to a regular commodity. However, this developing industry is threatened by the damage done by the western flower thrips (WFT), *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae), an insect showing high levels of insecticide resistance and apparently without effective natural enemies in this crop. This three-year study involved an examination of WFT biology, habitat, dispersal, and behaviour in nectarine orchards in the Okanagan and Similkameen valleys. The aim was to identify stages in the life cycle where a control effort could be focused and to aid in creating an appropriate pest management program for thrips.

Emergence and immigration into orchards were gradual and widespread processes. Egg-laying also occurred over an extended period of time, but with the bulk of eggs laid early in the development of nectarine buds, which is much earlier than prior studies had suggested. The lack of peak periods for these activities hinders control. Feeding by first generation larvae was identified as the primary cause of russetting damage to nectarine fruit.

Direct bud sampling was found to more efficient than using sticky cards to trap adult WFT. However, neither adult counts from sticky cards nor buds allowed me to predict either future larval or damage levels which makes it difficult to produce damage thresholds for this insect on this crop.

WFT tended to move into orchards from the direction of patches of wild land, but moved out of orchards in accordance with the dominant wind patterns. Immigration occurred mainly at ground level in the early spring. Flower preference studies suggested that exploitation of this flight behaviour by using a trap crop that blooms in the early spring is unlikely to succeed.

Orchards located adjacent to tracts of wild land appeared to be most at risk for immigration of WFT in early spring, and showed higher incidence of damaged fruit than orchards that are surrounded, and thus protected, by other orchards. Careful choice of planting sites appears to be one of the only control options available at present.



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## CHAPTER 1

### INTRODUCTION

#### 1.1 BACKGROUND

This three-year study involves a detailed examination of the biology of thrips, which are pests of nectarines in the Dry Central Interior, British Columbia. Nectarines are a relatively new crop for the tree fruit industry of British Columbia with two thirds of the acreage less than five years old. Efficient production of this crop is important since high-quality nectarines command a good price. British Columbia produces only a fraction of the crop that is sold both within the province and on prairie markets; therefore, the potential is appreciable provided good yields of an attractive product can be produced. However, this industry is threatened by the presence of thrips, assumed to be western flower thrips, *Frankliniella occidentalis* (Pergande) (Thysanoptera:Thripidae) (WFT). Thrips feeding on the immature buds cause scarring and deformation very early in the life of the fruit (during the blossom to petal-fall stage) which results in unmarketable culls. This damage is currently so extensive that a number of growers are considering removing nectarine orchards, and others are deterred from planting.

Although the western flower thrips has been implicated as the major pest, there was evidence prior to commencement of this study that more than one species of thrips is involved (L. Edwards, Integrated Crop Management Incorporated, pers. comm.). Presently there are no recommended treatments for control of thrips in nectarines. For apples, growers are advised to spray Diazinon immediately after petal fall, but in some years this is too late to prevent damage by thrips. A recent study showed that oviposition by thrips may occur as early as the pink stage in apple trees (Terry, 1991), which suggested that scheduling chemical spraying earlier than petal-fall would be advisable. Spraying at bloom is not recommended, however, because the insecticides are toxic to

pollinating bees. In addition, insecticidal control of thrips has been generally ineffective, possibly due to increased resistance of thrips to the chemicals applied (Immaraju *et al.*, 1992; Brodsgaard, 1994).

There is evidence that different varieties of nectarines exhibit different levels of damage. In 1991, a block of Harblaze in the Okanagan valley showed 40-60% damaged fruit and a block of Redgold had 50-60% damaged fruit, whereas other varieties sustained damage ranging from 15 to 30% (E.J. Hogue, Agriculture and Agri-Food Canada, pers. comm.). The severity of damage by thrips appears to vary with location and year, suggesting a relationship between damage and cultural or climatic conditions.

## Systematics

Western flower thrips belong to the order Thysanoptera, which literally means fringed wings, in reference to the finely fringed pair of wings possessed by all members of this order. There are approximately 5000 species of thrips, divided into two sub-orders, the Tubulifera and Terebrantia. The sub-order Tubulifera contains only one family, the Phlaeothripidae, and the Terebrantia contains four families: the Aelothripidae, Thripidae, Merothripidae and Heterothripidae (Stannard, 1968). Members of the Thripidae include most of the world's economically important species with most of these pests grouped in the sub-tribe Thripina. Eight hundred species of thrips are found in North America, distributed over 150 genera and 5 families, and making up just less than one sixth of the world's presently known thrips fauna. Thirty of those species are listed as injurious, and six are of major significance, namely, *Thrips tabaci* Lindeman, *Frankliniella occidentalis* (Pergande), *F. tritici* (Fitch), *Scirtothrips citri* Moulton, *Taeniothrips inconsequens* (Uzel) and *Thrips palmi* Karny. Unfortunately, the larvae of these species tend to lack easily seen characteristics which makes them very difficult to distinguish.

Adult thrips of different species may be distinguished at several levels. The external morphological characteristics used to determine thrips at the family level are: a) the



overall form of the antenna and sense cones; b) the shape of the forewing; and, c) secondary sexual characteristics, particularly the ovipositor, glandular areas and spines. At the generic level, structures used are: a) details of the antenna; b) the length and type of setae; c) the placement of maxillary stylets (in Tubulifera); d) the body sculpture; and, e) the foreleg armature. Finally, the features used to distinguish thrips at the specific level are: a) colour and chaetotaxy; b) head shape; c) individual antennal lengths; d) the arrangement of the prothoracic and wing setae; e) the sculpture of the metanotum; and, f) the shape of the pelta (in Tubulifera). Sex differentiation is relatively easy in Terebrantia, whereas in the Tubulifera, the female bears a short, internal rod (the fustis) lying just forward of the base of the tube (abdominal segment 10), which can be hard to identify.

The species *Frankliniella occidentalis* was first described by T. Pergande in 1895 and was placed into the genus *Euthrips* at that time (Pergande, 1895). H. Karny described the genus *Frankliniella* in 1910. Identification of *Frankliniella occidentalis* may be done using keys from Moulton (1948), Mound and Walker (1982), zur Strassen (1986) or Bournier and Bournier (1987).

Identification of *Frankliniella* spp. uses the following main characteristics in general: a) head shape/colour; b) the number of antennal segments (7 [only two species have 7] or 8) and their length; c) presence of trichomes on antennal segment III - IV, or the presence of sense cones [only one species has these]; d) whether the insect is brachypterous or macropterous; e) the length and position of the setae on the head (including the length and position of the ocular setae), pronotum, metanotum or tergites; and f) the length of the ctenidia.

For determination of larval *Frankliniella* spp. the primary setae are useful since their position and shape differs in different species. The setae and sense cones of the antennae and the setae of the legs are also useful.

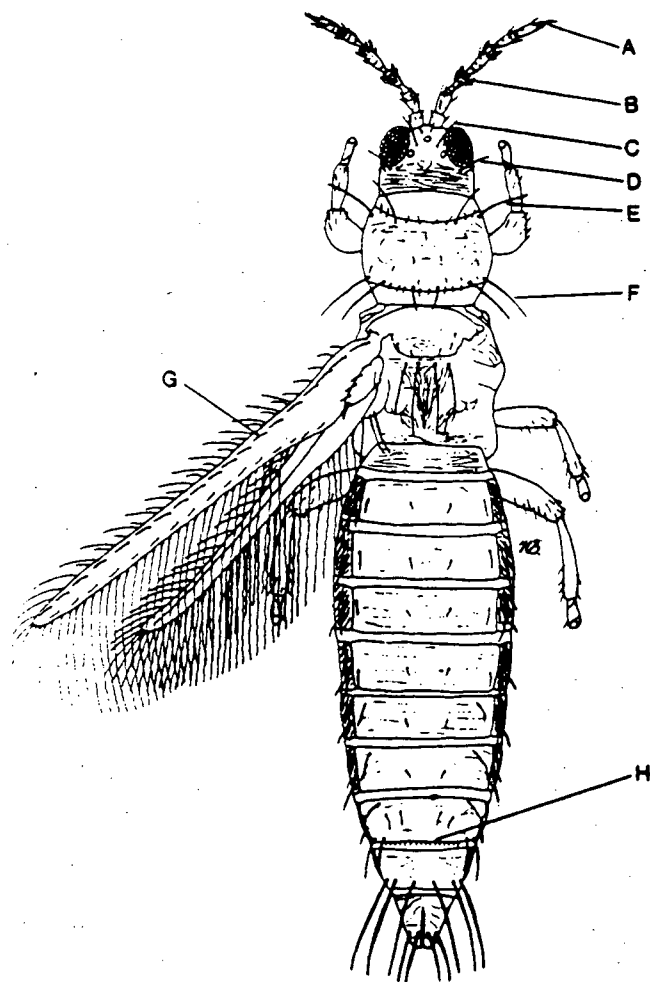
*Frankliniella occidentalis* adults are macropterous thrips with a length between 1.2 and 1.9 mm. Both larvae and adults have piercing/sucking mouthparts which are gathered

into a mouthcone. The front of this consists of the clypeus and labrum, the sides are made up of the galeate part of the maxillae with palps, and the back from the labium with palps. Inside the mouthcone are two thin maxillary stylets combined to form a tube, and a strong left mandibular stylet (the right one has degenerated) (Anathakrishnan, 1971; Chisholm and Lewis, 1984; Jones, 1954; Mound, 1971; Wardle and Simpson, 1927). Key characteristics of *F. occidentalis* are shown in Figure 1.1 (reproduced from Brodsgaard, 1989a).

Sex differentiation of adult *Frankliniella occidentalis* is relatively easy: males are usually smaller than females and the last three abdominal segments differ. In females the abdomen ends in a conical point, with the tip darker than the last abdominal segment and there is a saw-like ovipositor which is attached to abdominal segment 10. In males, the end of the abdomen is rounded or truncate, all the segments are the same colour (pale yellow) and there are several long setae protruding from the end of the abdomen that differ from those of females. There is also a pair of elongate orange glands that are only found in males. On sticky card specimens, these glands may often be damaged, and thus orange pigments are found in the terminal segments. In females, there may be an orange spot at the base of the ovipositor (Steve Nakahara, U.S.D.A., pers. comm.).

### **Host range and life cycle of western flower thrips**

Until recently, western flower thrips appeared to be restricted to western North America, from British Columbia to Mexico (Bailey, 1933; Bryan and Smith, 1956). By 1987, *Frankliniella occidentalis* had spread eastward and was established in Ontario and Nova Scotia greenhouses, and collections were made from field crops in Ontario and Quebec (Broadbent *et al.*, 1987). Western flower thrips now have a worldwide distribution, found throughout the Americas, Europe, New Zealand and Japan (Bartlett, 1988). This widespread distribution probably resulted from the movement of infested plant material.



**Figure 1.1** Diagram of a single female western flower thrips (reproduced from Brodsgaard, 1989a). Right wing pair is not drawn. Some key characters: A = Antennae 8-segmented. B = Forked trichomes on antennal segments III and IV. C = Interocellar setae III long and at the margin of the ocellar triangle. D = Postocular setae long. E = Anteroangular and one pair of anteromarginal setae long. F = Posteroangular and one pair of posteromarginal marginal setae long. G = Forewing with complete row of setae (16-20) on first vein. H = Tergite VIII with complete comb on posterior margin (females only).

Nectarines are only one of many host plants of western flower thrips (Yudin *et al.*, 1986; Cho *et al.*, 1989; Chamberlin *et al.*, 1992). Western flower thrips are polyphagous and have been collected from over 139 plant species representing 45 families and 23 orders. They have been found associated most commonly with plants from the families Leguminosae, Asteraceae and Cruciferae. Western flower thrips are believed to overwinter as sexually mature females in soil, in curled leaves, evergreen plants and in protected places such as under bark (Bailey, 1938). In California they overwinter primarily as adults, but there is limited reproduction at this time (Bailey, 1933). Adults and larvae of this species also occur on several crops and weeds in Texas through the winter (Stewart *et al.*, 1989). In the Dry Central Interior, however, temperatures are probably too low to permit reproduction at this time, and the adults become active in spring.

Western flower thrips are known to feed on pollen, nectar and plant tissue. In general, they are believed to remain within a flower until it withers or becomes otherwise unsuitable (Bailey, 1938). Larvae may be more dispersed than the adults as they also feed on leaf tissue (Pickett *et al.*, 1988). Upon entering the flower, the adults lay eggs close to the ovary as well as in less damaging positions such as on the sepals or in the leaves. Eggs are generally inserted singly at right angles to the plant surface into an incision made by the female's sawlike ovipositor. Eggs are opaque, reniform and approximately 0.25 by 0.5 mm in size. The eggs hatch after approximately four days at 26.5°C (Bryan and Smith, 1956). There are two larval stages, the first lasting one or two days, and the second lasting about three days at 26°C. These larvae feed on plant tissues and remain protected within the buds. They then drop to the ground or to a protected crevice of the plant (Bailey, 1938; Broadbent, 1986), and moult into a quiescent pseudopupal stage that lasts 4-5 days. This stage pupates in a loosely constructed cell and the adults emerge from the soil and move to the host plant. *Frankliniella occidentalis* adults are macropterous and between 1.2 and 1.9 mm in length (Figure 1.1). Males are generally smaller than females. Oviposition occurs within 72 hours of adult eclosion (Bryan and Smith, 1956). Adult female western flower

thrips lay between 25 and 100 eggs depending on temperature. Female *F. occidentalis* can live up to 40 days in the laboratory and 21 days in field cages (Bailey, 1938; Bryan and Smith, 1956). Males are apparently shorter-lived than females (Bailey, 1938). Both sexes are capable of dispersal, although they are not particularly strong fliers and apparently have no control of direction when wind speeds exceed 3.2 kph (Taylor, 1962; Lewis, 1973). Flight is favoured by high light intensity, low relative humidity, host plant unsuitability and the lack of strong winds (Morison, 1957). Female western flower thrips reproduce by haploid arrhenotoky in which unfertilized, haploid eggs develop into males, and fertilized diploid eggs develop into females. It has been suggested that, in greenhouses, the sex ratio of western flower thrips populations early in the growing period can be used to predict future population dynamics (Higgins and Myers, 1992).

### **Fruit Damage**

Most of the damage by this species is due to feeding by both adults and larvae which leads to the scarring and deformation of fruit (Lewis, 1973). Thrips have highly modified asymmetrical mouth parts that allow them to feed with a 'punch and suck' method (Borden, 1915). The epidermal and mesophyll cells are emptied of sap during feeding, which results in brown, yellow or silver necroses, the colour dependent upon the plant, as air enters the empty cells (Anathakrishnan, 1971; Chisholm and Lewis, 1984; Wardle and Simpson, 1927). In apples, large numbers of thrips feeding on flowers and young fruit can cause flowers to abort and fruit to be malformed and drop (Borden, 1915). In addition, some crops, including apples, are damaged by the egg-laying activities of the female (Venables, 1925; Childs, 1927; Terry and De-Grandi-Hoffman, 1988). In British Columbia apple orchards, most damage is caused by oviposition into young developing fruits (Madsen and Jack, 1966). Oviposition damage in the stamens and style may cause these tissues to wither and prevent pollination or may lead to 'pansy-spot' blemishes in apples when the oviposition occurs in the young fruits (Boyce, 1955). In general,

nectarines are damaged more severely than apples or other fruits. Injury appears as a stippling, mottling, russetting, or silvering of the skin. The discoloured area may be white, grey or yellow. Nectarines that are severely damaged when young may become distorted as they grow.

In addition to such direct damage to crops, western flower thrips are also able to transmit viral, bacterial and fungal diseases to their host plants (Bailey, 1935). Western flower thrips is the predominant vector of the tomato spotted wilt virus (TSWV), which has one of the widest known host ranges of any plant virus, including tomato, potato, lettuce, tobacco, gladiolus, onion, chili, and pineapple (Sakimura, 1962, 1963; Lewis, 1973; German *et al.*, 1992). Western flower thrips have also been shown to vector fire blight, *Erwinia amylovora* (Venables, 1925) and *Bacillus dianthi* (Bailey, 1935). Bailey (1935) also found fungal spores on the body surfaces of WFT which suggested that these insects can also vector fungal diseases.

### **Biological and cultural control**

A number of natural enemies of thrips have been documented including mirids, lygaeids, anthocorids, spiders, predatory thrips, and predatory mites (Letourneau and Altieri, 1983; Gillespie, 1989; Heidger and Nentwig, 1989; Yonce *et al.*, 1990a; Shipp and Whitfield, 1991; Bernardo, 1991; Loomans *et al.*, 1995). In addition, a variety of parasites and pathogens have been reported (Thompson, 1950; Wilson and Cooley, 1972; Lewis, 1973; Hall, 1981; Loomans *et al.*, 1995). Most attempts at using biological control agents to control thrips have been in greenhouses. In British Columbia, the phytoseiid mite, *Amblyseius cucumeris* (Oudemans) is used as a biological control agent of western flower thrips in cucumber and sweet pepper greenhouses. There is recent evidence that the anthocorid, *Orius tristicolor*, could be used simultaneously with *A. cucumeris* for effective biological control (Gillespie and Quiring, 1993).

The most commonly tested cultural controls include the application of mulches, use of various mechanical barriers, irrigation and flooding of land, deep ploughing, burning of crop debris and crop rotation (e.g., Bailey, 1938; Bullock, 1963; Greenough, 1985; Scott *et al.*, 1989; Yudin *et al.*, 1991). More recently, mechanical brushing of vegetable seedlings was found to result in a reduction of thrips damage and populations on eggplant, watermelon and tomato (Latimer and Oetting, 1994). Some of these methods are inapplicable for control of thrips in a perennial crop such as nectarines, where the land cannot be deep ploughed, burned or flooded. However, modification of the environment within and surrounding the orchards by weed management may have potential in reducing thrips populations.

## 1.2 OBJECTIVES

Most of the information about thrips in nectarines was anecdotal prior to the commencement of this study. It was unclear whether oviposition by adult females or feeding by first generation larvae is the major cause of damage to the nectarines. There was general confusion by growers as to the differences in damage caused by aphids and thrips. The number of generations of thrips occurring within the crop was unknown, as was the effect on the crop of later generations of larvae and adults. Information on the dispersal patterns of thrips into and out of the orchards and their alternative hosts was lacking. In addition, the location of their overwintering sites and the life-stage in which they overwinter had not been studied in this locality.

The lack of success and potential hazards of chemical control made it imperative to examine biological and cultural control methods. A detailed study of thrips biology, habitat, dispersal patterns and identification of their major natural enemies in the Dry Central Interior was therefore undertaken to identify stages in the life cycle where a control effort may be successful.

The main objectives of this study at the outset were:

- 1) Identification of thrips species and measurement of distribution, abundance and population structure within the nectarine orchards.**
- 2) Identification of damage thresholds and determination of practical sampling techniques for growers.**
- 3) Identification of overwintering sites.**
- 4) Measurement of spatial and temporal patterns of dispersal of thrips.**
- 5) Identification of natural enemies of thrips.**
- 6) Determination of suitable methods of cultural control.**

The main questions of interest as stated at the beginning of the study are listed as follows:

**1) Identification of the thrips species and measurement of distribution and abundance and population structure within nectarine orchards**

- a) Which species are most prevalent within the nectarine orchards?
- b) How many (potential) generations do they go through during the summer? How many of these generations take place within the orchards themselves?
- c) What is the sex-ratio of adults in the orchards? Does this change with density? Does this change over the season? What proportion of females collected in the field are virgins, and what proportion appear to be mated? Do these proportions change over the season?
- d) What is the role of fruit phenology on thrips distribution and abundance? At what stage are eggs laid? Where are thrips eggs laid? How does density of eggs/larvae vary on old versus young leaves versus flowers? Is there any relationship between adult density and adult weight/fecundity/survival of larvae?
- e) Is density of thrips late in the season correlated with density early in the season? How well can the latter be used to predict the former?



f) Where do the thrips pupate?

## **2) Identification of damage thresholds and determination of practical sampling techniques for growers**

a) What is the most susceptible period for fruit damage? Is most damage due to oviposition activity in the flower buds or to feeding by larvae and adults? Do females oviposit in the young or mature fruit later in the season? Are adult males feeding within the flowers/fruits?

b) At what density of thrips does control become necessary to reduce economic loss? What is the relationship between thrips densities and scarring of fruit? Is it possible to relate visual estimates of thrips densities over the season on flowers to levels of damage of mature fruit?

c) Do different trees differ in levels of damage and attack? Is this correlated with the date of budburst, wet/dry weight of leaves, age of trees, weather conditions, size/height of trees, moisture in the ground, total number of leaves/flowers? Is there any correlation between leaf/flower size and density of thrips?

d) Is there any correlation between the density of thrips estimated by sampling buds/flowers from a tree, and the estimates from sticky traps hung within the tree? Is there any correlation between the former values and estimates of thrips density by non-invasive methods, such as shaking of flower heads over a white surface?

## **3) Identification of overwintering sites**

a) Where do the thrips overwinter?

b) In what stage(s) of the life-cycle do they overwinter?

c) What are the preferred hosts of thrips? Do different plants support different densities of thrips? Are there different levels of fecundity and survival on different plants? Do thrips prefer nectarines over other flowering plants?

#### **4) Measurement of spatial and temporal patterns of dispersal of thrips**

a) When do thrips fly into and out of the orchards? Do these periods of immigration and emigration peak at distinct times or take place over long periods of time? Is migration into the orchard associated with drying up of flowers of alternative hosts? Is migration from the orchard associated with petal fall?

b) What is the spatial colonization pattern of thrips in nectarine orchards? At what height are thrips flying? What is the effect of wind direction? What are the temporal scales of activity? When are the activity peaks-when are thrips flying? Do these coincide with generation times?

c) Do peaks of dispersal coincide with generation times?

#### **5) Identification of natural enemies and biological control**

In general, the lack of biological control agents found early in spring while larval thrips are causing damage to the developing nectarine buds resulted in an abandonment of this objective.

#### **6) Cultural control of thrips**

a) Do thrips densities show any correlation with type of ground cover?

b) How do thrips movement patterns vary in different types of vegetation both within and surrounding an orchard?

### 1.3 STUDY SITES

Work was carried out in both the Okanagan and Similkameen Valleys, in the Dry Central interior of British Columbia, Canada. Field work over the three years was carried out in 12 different orchards in total. Ten of these were located in the Similkameen valley close to Keremeos ( $49^{\circ} 12'N$   $119^{\circ} 47'W$ , 430 m above sea level) and two in the Dry Central Interior, close to Summerland ( $49^{\circ} 34'N$   $119^{\circ} 39'W$ , 454 m above sea level). Laboratory work was carried out at Agriculture and Agri-Food Canada Research Centre in Summerland during 1993-4 and at the Department of Plant Science, University of British Columbia, during 1995. Wildflower collections were made over various areas in the two valleys, but primarily in the Kobau Mountain and Ashnola River valley areas of the Similkameen valley (data not in thesis).

All orchards used in these studies were located on the lower slopes of the Okanagan and Similkameen Valleys. These areas may be broadly categorized as the "Dry Interior" and can be defined as areas where the summers are hot and arid and the winters are cold and dry. Maximum summer temperatures in these regions reach upto  $40^{\circ}C$  and minimum winter temperatures may reach as low as  $-30^{\circ}C$ , although winter temperatures down to  $-10^{\circ}C$  are more typical. The degree of aridity in this region is due to the effect of the rainshadow produced by the Coast Mountains. December and January are usually the wettest months, and the driest months are September and October. Climate is somewhat moderated in Summerland, due to the proximity of the large Okanagan Lake.

In this region of British Columbia, weather patterns can change dramatically over a short period of time due to the terrain: a common local pattern is known as the mountain-valley or slope-valley wind. At night, the air on the valley slope undergoes radiative cooling and sinks to the valley bottom. Later in the day, radiational heating of the land may lead to the production of an upslope wind near midday or later in the afternoon. In narrow, steep-sided valleys such as the Okanagan and Similkameen valleys, a cross-valley transport

system may develop when radiative heating occurs on only one slope. The warm air rising up the heated side is replaced by air flowing across the valley floor from the shaded side. A return flow occurs near the ridge tops to compensate for the lower crossflow, so that the circulation pattern is complete (Wellington and Trimble, 1984).

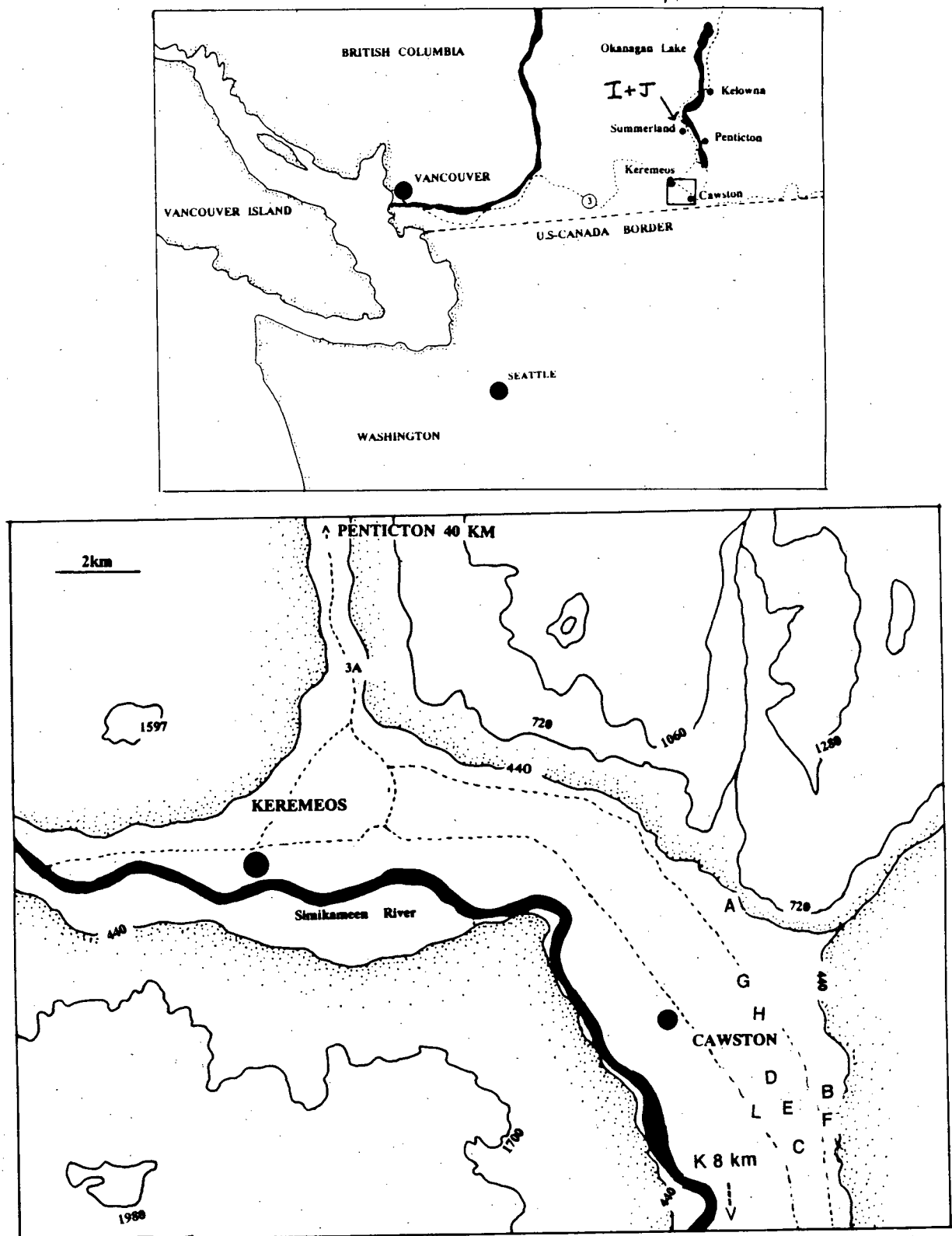
The dry interior region is characterized by widely spaced bunchgrasses and a well-developed cryptogam crust (Meidinger and Pojar, 1991). Typically, this bunchgrass zone extends from valley bottoms up to elevations between 700 and 1000 m. The typical cover consists of 10-15% shrubs, 60% bunchgrasses and 25-35% cryptogams. The characteristic climax vegetation in the southern Okanagan is bluebunch wheatgrass (*Agropyron spicatum* Pursh), together with big sagebrush (*Artemisia tridentata* Nutt.), low pussytoes, (*Antennaria dimorpha* (Nutt.)), brittle prickly pear cactus (*Opuntia fragilis* (Nutt.)), and rabbitbrush (*Chrysothamnus nauseosus* (Pallas)). Soils in this region are typically silty clay loam to sandy loam Brown Chernozems or Regosols. This region has very high agricultural productivity, and supports orchards, vineyards and alfalfa with the aid of irrigation.

During the first season, (1993), work began on the first three objectives. Ten nectarine blocks were used for this study: eight in the Cawston/Keremeos area (A, B, C, D, E, F, G, H) and two in the Summerland area (I, J) (Figure 1.2). These sites were selected in conjunction with advice from Linda Edwards (I.C.M.I.) and E. Hogue (Agriculture and Agri-Food Canada).

During the second field season of this study, work was continued on Objectives 1, 2, 3, and 4, and initiated on Objective 6. Studies during 1994 were carried out in eleven orchards in total. Nine of these are in Cawston with five operating conventionally (A, B, D, F, H), two in the first year of conversion to organic (C, E) and two fully organic (K, L). The other two are in Summerland and are both fully conventional (I, J) (Figure 1-2).

Studies during 1995 were carried out primarily in two nectarine orchards (B&K), and one crabapple orchard (M) in the Similkameen valley, and in one orchard in

Summerland (J), and primarily concentrated on flower preference behaviour of western flower thrips as well as the impact of neem as a botanical insecticide. In chapter 7, orchards B, K and M are labelled as orchards A, B and C.



**Figure 1.2** Map showing the location of the twelve nectarine orchards (A-L) used for studies between 1993 and 1995 in the Dry Central Interior, British Columbia, Canada.

## CHAPTER 2

### POPULATION DYNAMICS PART I

#### **Population Dynamics of Western Flower Thrips in Nectarine Orchards in the Dry Central Interior, British Columbia, Canada**

**ABSTRACT** The distribution and abundance of western flower thrips, *Frankliniella occidentalis* (Thysanoptera: Thripidae) (WFT) are compared among 11 nectarine orchards located within the Okanagan and Similkameen Valleys, British Columbia, Canada during 1993 and 1994. Abundance of thrips is related to the orchard location, stage of nectarine flower development (within orchard and within tree) and temperature. Distribution of both adult and larval western flower thrips (WFT) within trees and within orchards is heterogenous. Overwintering behaviour and season-long population dynamics of WFT are studied both in orchards and in the areas surrounding orchards, and the life cycle of WFT within this region is described.

**KEY WORDS** *Frankliniella occidentalis*, nectarine, distribution and abundance, overwintering behaviour

### 2.1 INTRODUCTION

Nectarine (*Prunus persica* (L.) Batsch) production in the Dry Central Interior, British Columbia, has recently grown from being a minor specialty crop to having a regular commodity status. However, this developing industry is threatened by the damage done by thrips (generally assumed to be the western flower thrips (*Frankliniella occidentalis* (Pergande) [Thysanoptera: Thripidae]) to the fruit in early spring. Appropriate integrated pest management strategies for this insect have not been developed because information on its population dynamics in this region is lacking. The species composition of thrips within nectarine orchards, the identity of the species responsible for damage, the specific time

during which damage occurs, spatial and temporal patterns of abundance of western flower thrips, as well as details of its overwintering and emergence had not been previously identified. The number of generations of thrips occurring in nectarines also was unknown, as was the effect on the crop of later generations of larvae and adults. Although a pre-bloom application of the insecticide Diazinon is recommended in this region for control of WFT on apple, its increasing lack of success due to resistance and the negative impact of chemical control on beneficial insects such as pollinating bees have highlighted the need to pursue biological and cultural methods of control for thrips. A detailed study of thrips population dynamics was thus required to identify stages in the life cycle in which a control effort may be successful and to aid in creating an appropriate pest management program for thrips.

Determination of the overwintering sites and the timing of emergence of WFT in the spring is critical for comprehension of the life history of this insect pest in this region. Western flower thrips are believed to overwinter as sexually mature females in soil, in curled leaves, evergreen plants and in protected places such as under bark (Bailey, 1938). In California they overwinter primarily as adults, and limited reproduction continues during this time (Bailey, 1933; LaRue *et al.*, 1972). Adults and larvae of this species also occur on several crops and weeds in Texas through the winter (Stewart *et al.*, 1989). In New Mexico and Colorado, adults are believed to hibernate during the winter. This has also recently been found to be the case in Pennsylvania (Felland *et al.*, 1993a). Similarly, temperatures are believed to be too low to permit reproduction during the winter in the Dry Central Interior, and it is likely that the adults do not become active until spring. It has been suggested that WFT overwinter in areas of sagebrush and wild land bordering orchards in the Okanagan (Venables, 1925; Madsen and Jack, 1966; E. Hogue. pers. comm).

Information on factors that may affect the density of thrips -- orchard, tree or within-tree location, time of day, time of year, and stage of development of nectarine buds



-- must be obtained so that appropriate sampling programs can be designed and the influence of these various factors elucidated. Lewis (1973) reported considerable variation in seasonal thrips populations and injury levels. There also is evidence that densities of WFT may vary spatially both within and among plants in a field (Salguero Navas *et al.*, 1991a). Adults are known to be more concentrated in flowers as they prefer feeding on nectar and pollen, whereas larvae may be more dispersed as these also feed off leaf tissue (Pickett *et al.*, 1988). Terry and DeGrandi-Hoffman (1988) found that the population density of WFT within apple clusters was correlated with the number of open blossoms throughout peak bloom (taken to be 50-60% bloom).

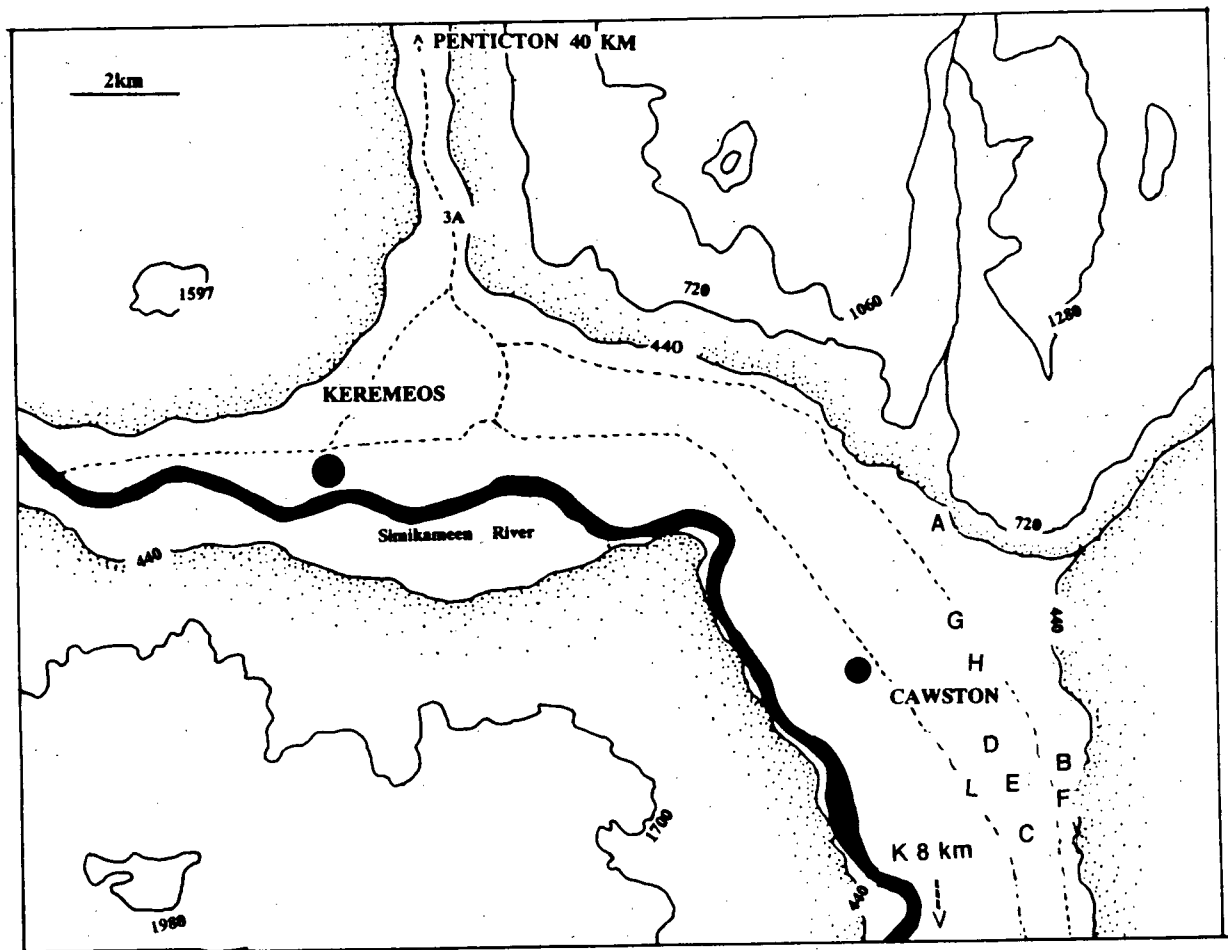
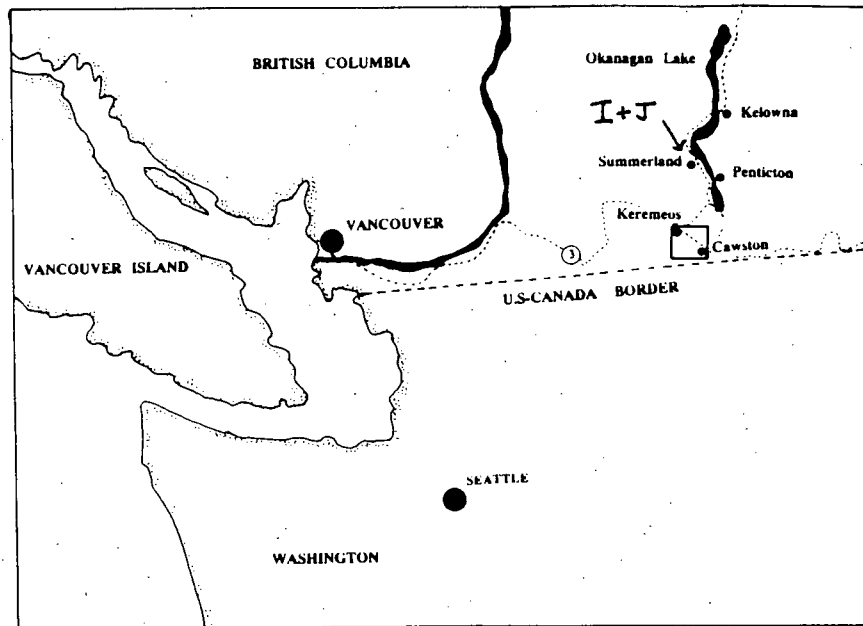
Thus, the main objectives of this study were to obtain information on location of overwintering sites, population dynamics and phenology of WFT both within and around orchards. The influence of time of day, position of buds/leaves on the tree, and position of trees within an orchard were examined for their effect on density estimates by sampling.

## 2.2 MATERIALS AND METHODS

Studies were conducted in ten orchards in 1993 (A-J) and eleven orchards in 1994 (A-F, H-L) all located in the Dry Central Interior, British Columbia (Figure 2.1). Ten of these are located in the southern end of this region, close to Cawston, with six operating conventionally (A, B, D, F, G, H), two in the first year (in 1993) of a three year conversion to organic (C, E) and two fully organic (K, L). The other two are located further north, close to Summerland and are both conventional (I, J). Conventional orchards received herbicide, pesticide and various other chemical sprays throughout the growing season. The varieties of nectarine within each orchard are shown in Table 2.1.

**Table 2.1** Varieties of nectarine grown in the various study orchards used for the population dynamics studies 1993-4

| Orchard | Varieties  | Age in 1993 |
|---------|--|-------------|
| A       | Fantasia<br>Redgold                                      | 6           |
| B       | Redgold  | 5           |
| C       | Redgold<br>Early Sungrand                                | 8-10        |
| D       | Fantasia<br>Redgold                                      | 8<br>3      |
| E       | Redgold<br>Early Sungrand                                | 3           |
| F       | Crimsongold<br>Redgold                                   | 10-15       |
| G       | Redgold<br>60 Independence                               | 2-4         |
| H       | Flavourtop<br>60 Independence                            | 7           |
| I       | Redgold<br>Fantasia                                      | 3           |
| J       | Harko<br>Harblaze<br>Earliscarlet<br>Early Sungrand      | 4           |
| K       | Earliscarlet<br>Early Sungrand<br>Redgold<br>Crimsongold | 5           |
| L       | Redgold  | 3           |



**Figure 2.1** Location of orchards A-L in the Dry Central Interior, British Columbia, Canada.

**Overwintering Studies.** *1993:* Sampling of potential overwintering sites of thrips took place in March using emergence traps (in orchards A, B, C and in wild areas close to orchards A and B) and by extraction of thrips from leaf litter and soil samples with Berlese funnels (in orchards A, C, I and J). Unit volumes of leaf litter and soil were not quantified but may be estimated as approximately 125 cm<sup>3</sup>. Emergence traps (modified version of Tanigoshi and Moreno's (1981) traps) were positioned beneath plants and trees within and bordering the orchards, to collect adults emerging from the soil. These were constructed using 20 cm long sections of 10 cm diameter white PVC piping. Two 2 cm diameter holes were cut from either side of the pipe to allow aeration and prevent condensation build-up within the trap. These holes were sealed with Nytex screening using a glue gun to prevent escape of thrips. One end of the piping was buried into the ground and one half of a plastic petri dish was placed over the uppermost open end of pipe. The underside of the petri dish was coated with tanglefoot glue to trap the thrips flying upwards. A piece of clear plastic was wrapped over the petri dish with an elastic band to prevent accidental loss of the petri dishes and to prevent entry of water. A total of fifty traps were placed in the five locations on 27 March and retrieved on 15 April. Subsamples of thrips collected from the Berlese funnels were mounted on microscope slides and sent to Dr. Sueo Nakahara, U.S.D.A., Maryland for identification.

*1994:* Emergence of thrips in nectarine orchards was monitored in four orchards (B, E, F, and J) using emergence traps and bark traps. The latter were made by wrapping bands of Parafilm around a branch and coating the bands in Stickum®. Three of the orchards (B, F, and J) had large adjacent areas of wild land. On 1 March, 15 emergence traps were set up in each orchard (three under each of five trees in those orchards where tree diameter was less than 2m {E, F, and J}, and five under each of three trees in orchard B where tree diameter was greater than 3m) and 15 were set up in each of the three areas of wild land. In addition, two sticky bands were wrapped on each of five trees in all four orchards. These bark traps were collected and replaced every few days until 30 March. By

that date, temperatures were high enough to permit thrips flight, thus catches on the sticky bands could not necessarily be attributed to emergence from resting places on the bark only. Emergence traps were monitored every few days until zero counts within the orchards indicated that the first emergence was complete (between 19 and 26 April). On each sampling date, the petri dishes were removed from the emergence traps, the thrips stuck to the Tanglefoot were counted, and a new petri dish was placed over the piping. These data are used to define the timing of the start of emergence and the duration of emergence from the ground. In addition, the amount of emergence from trees and ground was quantified and compared among the different orchard locations and from wild land.

In addition to ground traps and bark traps, yellow sticky cards were placed in pairs on each of four one-metre-high posts in areas of wild land close to both orchards A and B in 1993 and 1994 to determine when thrips began to fly into orchards, and how abundance varied over the season. In 1993, cards were placed outside on 7 April and replaced every few days until the final collection on 1 June. In 1994, the sticky cards were placed out on 23 April and monitored every few days until 30 May. After 30 May, sticky cards were placed out in orchards once per month and collected 12 days later until 20 November.

**Distribution and Abundance.** *Sampling.* The changes in abundance of thrips in both years within all eleven orchards was monitored from dormant bud to husk-fall stage by sampling 8-12 nectarine buds from each of six to eight trees within each sample orchard. Bud sampling was carried out between 7 April and 13 May in 1993, and between 28 March and 7 May in 1994. Sample trees were selected randomly, after stratifying the orchards into four quarters. The same trees were used both years. Two to three buds were picked randomly from each of the four cardinal quarters (N,E,S,W) of each tree and were placed immediately into Ziploc® bags to be taken back to the laboratory. Stage of bloom and the density and species of thrips found were recorded. Approximately 50% of the larval samples were placed into vials of 70% ethanol and were counted when time

permitted. Larvae were stained by dropping 1 ml of Rose Bengal stain into each vial. After 2 weeks the contents of the vial were poured through a Nytex (85 $\mu$ m mesh) filter. The buds were teased apart with forceps and rinsed with water over the filter. The vial and its lid were also rinsed with water over the filter. The filter was then turned upside down and its contents washed with a minimal amount of water into a petri dish. The larvae stained bright pink and were easily visible in the water. They were counted using a dissecting microscope at 120x power. All adult samples were counted as they were collected. In 1993, three bud counts were made between petal fall and husk fall, and the larval stage and number of larvae per bud were recorded. In 1994, three to five larval counts were made depending upon the orchard, with orchards that developed most quickly through the stages of petal fall to husk drop receiving the least counts.

In 1994, bud sampling was carried out on an almost daily basis in orchard E so that changes in abundance of adults and larvae could be examined more closely.

In 1993 and 1994, we also examined nectarine buds directly in the field so that we could determine the absolute number of larvae within each bud, which could not be ascertained when samples of 12 buds were pooled into bags and brought back to the laboratory. Samples of 50 randomly chosen buds were examined within each orchard.

In 1994, the ground cover within orchards B and J was sampled at the same times as the nectarine buds and the density of WFT per flower recorded. Ground cover sampling was continued in these orchards until 20 November.

In 1993 only, the density of larval thrips falling into the ground to pupate was assessed using drop traps in three orchards (A, B & H). These traps consisted of sheets of stickum-coated coroplast (20 cm by 20 cm) which were anchored 8 cm above the soil surface using four long nails, one in each corner. Four traps were placed under each of six randomly chosen trees in orchards A and B, and under each of five randomly chosen trees in orchard H. These were placed outside on 15 May 1993, at the time when larvae were developing within petal fall buds, and retrieved on 21 May (A), 22 May (H) and 23 May

(B), by which time husk fall had occurred. Tree area was estimated by measuring from the base of the trunk to the outside edge of the canopy using a measuring tape to determine tree radius. We measured the highest and lowest radii for the tree and took the mean of these values, using this mean to determine area. Abundance of thrips on the nectarine trees was monitored twice in 1993 after this stage, to determine whether thrips were reproducing on nectarine leaves or fruit.

In 1994 only, in addition to the bud counts, general trends of aerial populations were monitored using yellow sticky cards which were placed in pairs on four one-metre-high posts within orchards A, B, and E. The sticky cards were placed out on 23 April and monitored every few days until 30 May. After this time, sticky cards were placed in orchards once per month and collected 12 days later until 20 November.

Thus, in 1994, sticky cards were collected both from areas of wild land (as part of the overwintering study) and within orchards. Therefore, the changes in density of WFT over the season could be compared within orchards and within wild areas and a comparison could be made between the density of WFT caught on the sticky cards and those from the bud samples.

*Damage assessment* In both years fruit was rated for injury by thrips twice between petal fall and harvest using a numerical scale from no damage at 1, slight scarring at 2, to severe deformation at 7. In 1993, damage assessments took place on 3 and 26 June for the southern orchards, and on 28 June and 3 July for the northern orchards. In 1994, fruit damage was assessed on 18/19 May and 25 May (shortly after husk-drop) and again on 10 and 12 June (about half-sized fruit) for the southern and northern orchards, respectively. Although fruit damage was assessed on several dates during both years, we decided to use the first damage assessment only (June 3 and 28 for 1993, and 18/19 May and 10 June for 1994, for the southern and northern orchards, respectively) because fruit thinning after these dates removed any conspicuously damaged fruit.

**Factors affecting abundance.** Six studies were carried out over the two years:

a. *Analysis of the relationship between tree location within orchards and density of adult and larval thrips and subsequent fruit damage.*

In 1993, density of adult and larval thrips was determined every three days between 7 April and petal fall from 12 buds per tree, and fruit damage was assessed from 15 fruit per tree from each of 15 trees in three orchards: B, I and J. The orchards were stratified into five sections and three trees were randomly chosen from each the four outside sections of the orchards, with the final three trees randomly chosen from the "inside" section of the orchards. Data were analysed using ANOVA to determine whether total number of adult and larval thrips per bud caught during the period of bud development and mean fruit damage per tree varied with position.

b. *Analysis of the relationship between position within a tree and the density of adult and larval thrips.*

Counts of adult thrips were made from eight trees in two of the orchards (C & E) twice in 1993. On four of the trees, 12 buds were taken from both the 'inside' (area closer to the trunk) and 'outside' (area distal from the trunk) portions of the tree (total of 24 buds) and, on the other four trees, four buds were taken from each of the four cardinal directions (N,E,S,W) within both the upper half and lower half of the canopy (total of 32 buds). In 1994, adult and larval thrips were sampled in the same two orchards from 16 buds taken from each of the inner/outer (IN/OUT) portions of eight trees and from 16 buds taken from each of the upper/lower (UP/DOWN) portions of a further eight trees to determine whether there was a preferred location for residence and/or egg-laying. Paired t-tests were used to compare densities of WFT between locations. On a second occasion, larval thrips were collected from 12 buds taken from each of four areas of a tree: Up-In, Up-out, Down-In, and Down-Out for a total of 48 buds per tree. Data were analysed using ANOVA .

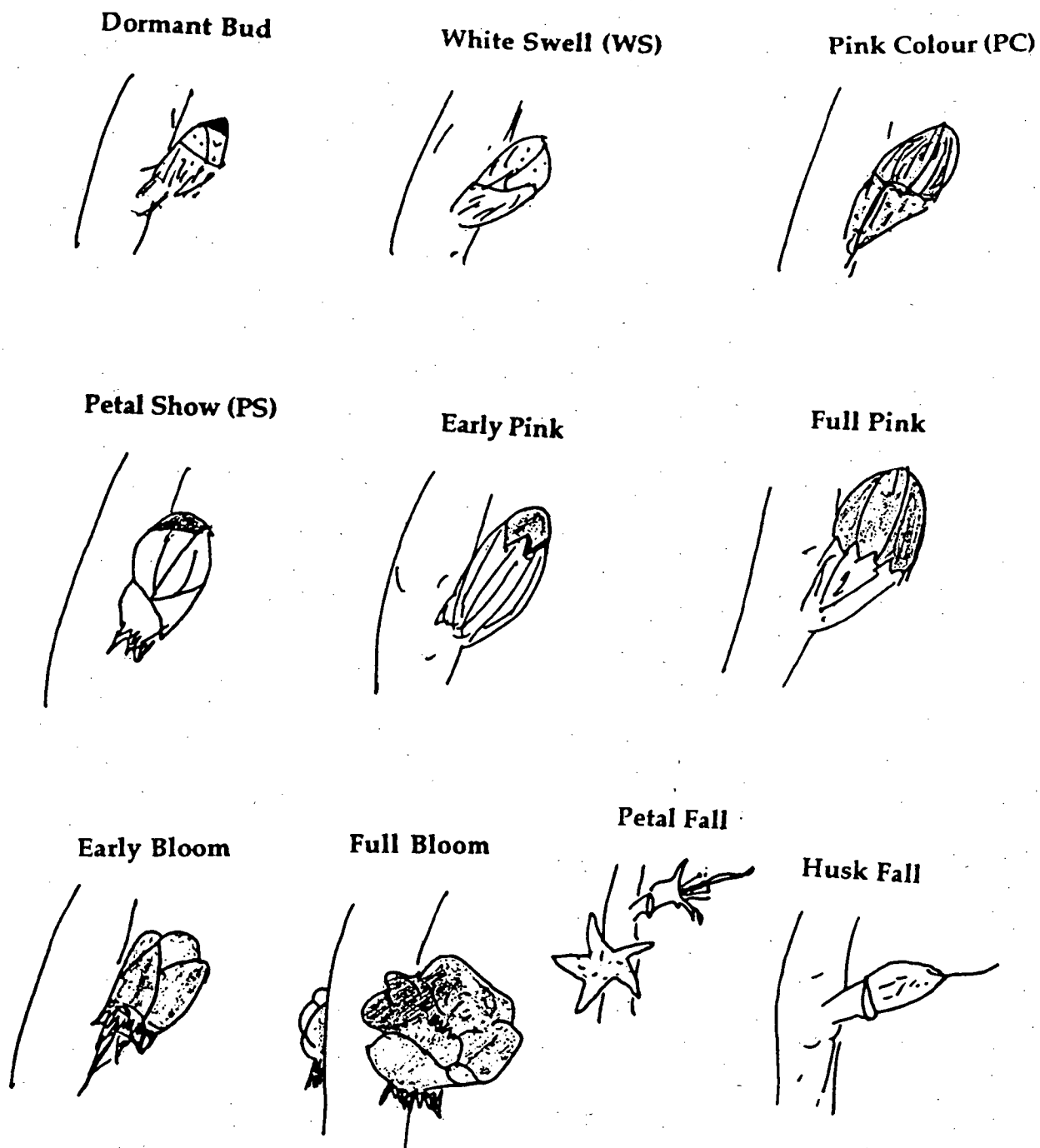


*c. Analysis of the relationship between the stage of development of nectarine buds and the density of adult thrips.*

At any one time, the buds on a tree are at different stages of development, with those at the end of the branches often most advanced in comparison with those on the rest of the tree. At various times throughout bud development, between 12 and 24 buds of two different developmental stages were randomly removed from a total of 8-12 randomly chosen trees and the number of adult WFT counted. Developmental stages of nectarine buds are described as follows: (1) **silver tip**: bud is completely dormant; (2) **white swell** (ws): bud is beginning to swell and come out of dormancy; (3) **pink colour** (pc) bud is no longer silver but appears dark pink, no petal is yet apparent however; (4) early/mid/late **petal show** (eps/mps/lps): these are varying stages as petal becomes increasingly apparent from the bud, which is not yet at the full pink stage; (5) **full pink**: often labelled the "popcorn stage"; (6) **early/mid/late bloom**; varying stages of bloom progression, with dark pink and soft petals by late bloom, which is close to the point when they will drop off the bud; (7) **petal fall**; (8) **husk fall** (Figure 2.2). Comparisons were made of the density of WFT per bud at the "silver tip/white swell" versus "pink colour", "pink colour" versus "early petal show", "early petal show" versus "pink" stage and the "pink" versus "bloom" stage for each of several orchards for both years. Paired t-tests were used to determine whether there were any significant differences in abundance of WFT per bud for each pair of developmental stages.

*d. Analysis of the relationship between tree size and density of adult and larval thrips and subsequent fruit damage.*

The relationship between a) the total number of adult and larval thrips per nectarine bud per tree collected between silver tip and petal fall in each orchard in 1993 and b) the subsequent mean fruit damage per tree (based on damage assessments made on 10 to 25 fruit per tree) and the height and canopy radius of the trees was investigated using simple linear regression.



**Figure 2.2** Diagram of the various stages of development of nectarine buds from dormancy (silver tip (st)), white swell (ws), pink colour (pc), petal show (ps), pink, bloom, petal fall, to husk fall.

e. *Analysis of the effect of time of day on adult thrips density estimates.*

On two occasions in 1993, adult thrips were collected from 12 buds from each of 8 randomly chosen trees in orchard B at 0700, 1200, and 1800 to determine whether the time of sampling is a critical factor in determining thrips density. On 21 April 1994, adult thrips were collected from twelve buds from 8 randomly chosen trees from three orchards (A, C, & K) at 0830, 1330 and 1800. One-way ANOVA was used to determine whether abundance of WFT varied significantly with the time of day of sampling.

f. *Analysis of the relationship between pruning/thinning date and fruit damage.*

Pruning and blossom thinning were carried out for the purposes of this study on two dates in 1993 in orchard E such that four of the sample trees in each orchard were pruned and thinned early (before full pink stage) and the other four received these treatments between full bloom and petal fall. Independent t-tests were used to compare densities of adult WFT collected pre-petal fall, peak larval densities, and mean fruit damage per tree between the two sets of trees.

**Thrips association with fruit damage.** To try to determine which species of thrips (WFT or *Thrips fallaciosus* or both {see Results: Distribution and Abundance: *Species*}) were responsible for the damage, and whether a particular WFT morph may be causing most damage, larvae were collected from petal fall buds and reared through to adults from two of the orchards (C & J) in both years. Rearing took place on leaves of Pinto beans placed in pots of water inside mason jars and a layer of peat moss 2.5 cm thick was provided for pupation. The jars were held at a temperature of 25°C inside an incubator. Numbers of male and female progeny, and the numbers of female adults of each morph (dark, intermediate or pale) of WFT, was recorded.

**Larval movement.** Various species of ants and ladybugs were commonly found on trees when WFT larvae were hatching within buds, which prompted us to examine

whether larvae were found moving around on tree limbs and thus could be a food source for these predators. In 1994, sticky bands of tanglefoot-coated parafilm were wound tightly around branches both close to and far from buds, as well as around the tree trunks of each of three trees in orchards A, F, I, J & K. A total of 18 bands were placed on each tree prior to larval hatch and three bands per tree were retrieved every day for six days after petal fall. These were examined for larvae under a dissecting microscope at 120x power.

**Data Analysis.** A level of  $P < 0.05$  was taken to be significant for all statistical comparisons. Comparison of abundance of adult and larval WFT among orchards was carried out using ANOVA. Where heteroscedasticity precluded the use of ANOVA, and where numbers could not be adequately transformed, the non-parametric Kruskal-Wallis test was used. Tukey's HSD test was used for all post-hoc comparisons of ANOVA results. A Mann-Whitney U test was used for post-hoc comparisons of all Kruskal-Wallis results with a Bonferroni adjustment to control the experiment-wise probability of a type I error to 5%. Averages are presented in the text as mean  $\pm$  standard error.

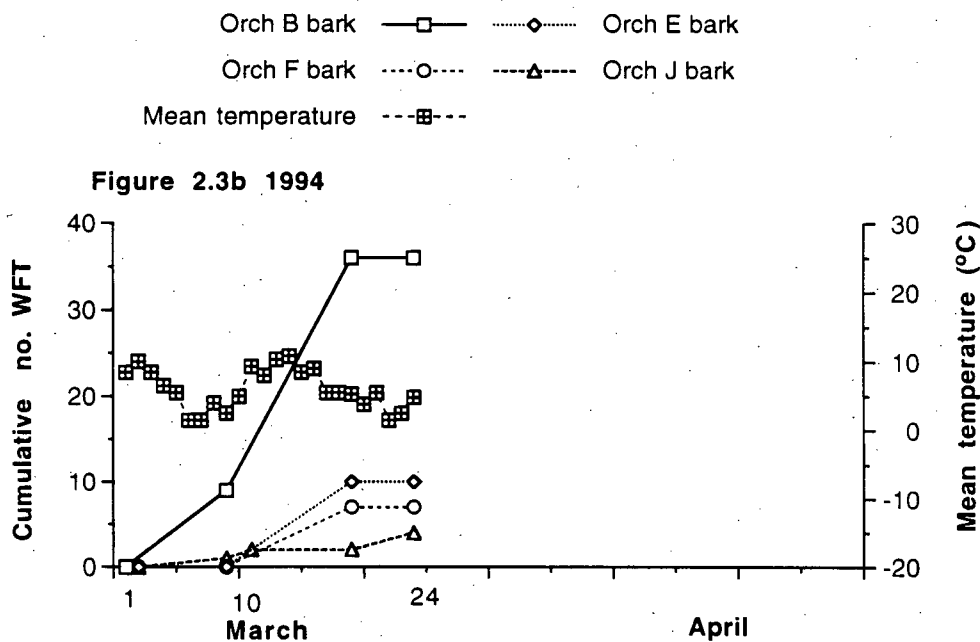
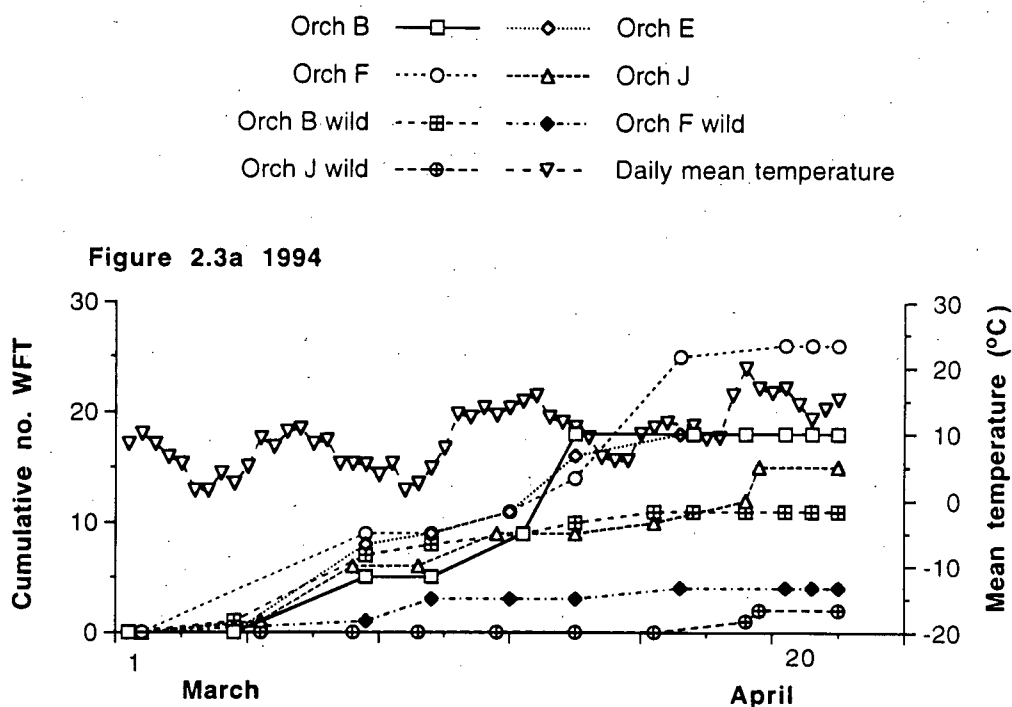
## 2.3 RESULTS

**Overwintering studies. Emergence.** The low number of thrips caught per emergence trap in both years precluded statistical analysis.

*1993:* WFT were first caught in traps on 11 March. By 15 April, each trap contained between 0 to 4 thrips per trap, with means  $\pm$  standard error of  $0.7 \pm 0.4$ ,  $0.4 \pm 0.2$ , and  $0.4 \pm 0.2$  per trap for Orchard A, I and J, respectively. Very low numbers of thrips were caught in the wild land traps: a mean  $\pm$  standard error of  $0.1 \pm 0.1$  per trap in wild land bordering orchard A and a mean  $\pm$  standard error of  $0.2 \pm 0.2$  per trap from wild land bordering orchard J. No thrips were caught in the 10 emergence traps placed in orchard C. The species caught were identified as adult female WFT.

Leaf litter samples taken from A, I and J also yielded low numbers of WFT: 2 pale WFT from A, 1 pale WFT from I and 1 dark WFT from J. Soil samples yielded 1 pale and 1 dark WFT from orchard A and 1 dark WFT from orchard J.

*1994:* Emergence of thrips from the ground was first monitored on 9 March in the Keremeos orchards B, E and F (located further south) and on 11 March in orchard J located further north in Summerland. Emergence began while the trees were still at the dormant stage in all orchards and appeared to occur once temperatures exceeded 10°C. The bulk of emergence from the ground occurred between 9 and 31 March, and was relatively continuous, although periods of low or zero emergence coincided with periods when air temperatures fell, which no doubt led to drops in ground temperature (Figure 2.3a). Overall, means of  $1.2 \pm 0.24$ ,  $1.2 \pm 0.37$ ,  $1.73 \pm 0.45$  and  $1 \pm 0.14$  WFT emerged per trap in orchards B, E, F and J, respectively. These values translate into mean estimates of 153, 153, 220 and 127 thrips emerging per square metre under the trees in these orchards. A mean  $\pm$  SE of  $0.7 \pm 0.21$ ,  $0.27 \pm 0.13$  and  $0.13 \pm 0.09$  WFT emerged per wild land trap located close to orchard B, F and J, respectively, which translates to a mean of 89, 34 and 17 thrips per square metre. Emergence of thrips from the ground was zero by mid April



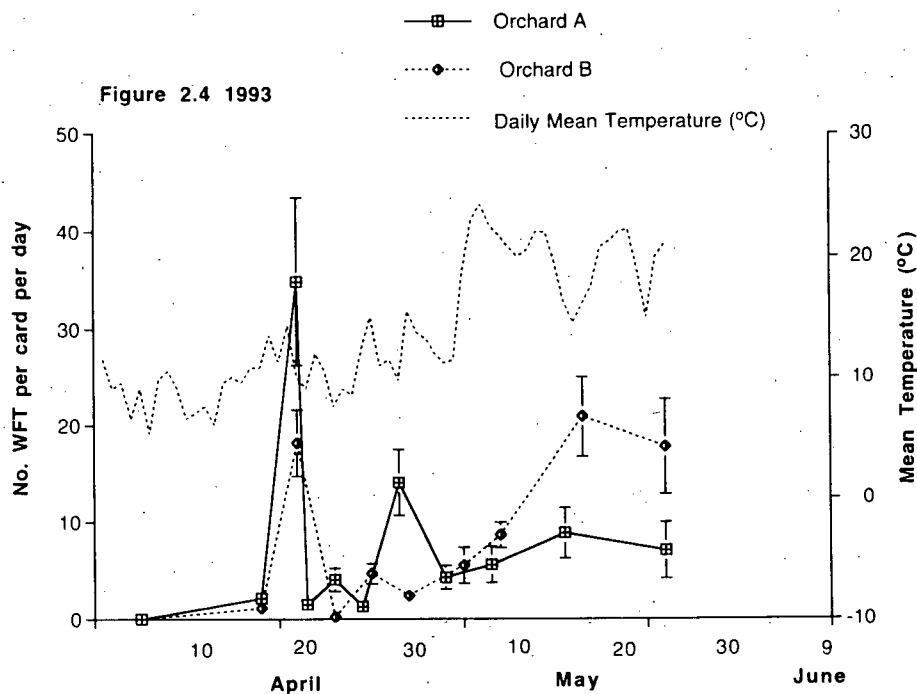
**Figure 2.3a,b** Emergence of WFT a) from the ground in orchards B, E, F & J and from wild land adjacent to orchards B, F & J, and daily air temperatures from 1 March - 23 April 1994 in Keremeos; and b) Emergence of WFT from sticky bands wrapped on bark of nectarine trees from orchards B, E, F & J from 1 March - 24 March 1994.

and thus first emergence of overwintered adults was assumed to be complete by this date. Thrips were also caught on the sticky bands, suggesting that there is substantial overwintering within the tree bark (Figure 2.3b). It appeared that thrips were active on trees, albeit at low levels, prior to their being caught in emergence traps. The emerging thrips were all adult WFT females.

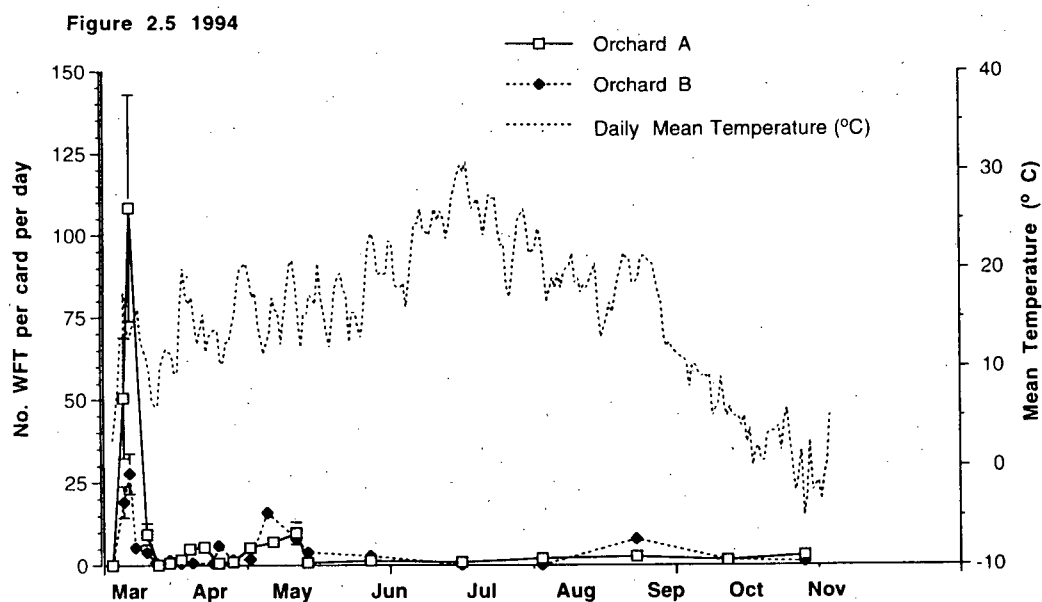
*Flight in wild lands. 1993:* Counts from the sticky cards in wild areas located adjacent to both orchard A and B showed that flight of WFT into orchards began in early to mid-April. Numbers in wild areas peaked on April 22 at both locations (orchards A & B) and then gradually built up again at the beginning of May, probably corresponding to the emergence of the first generation (Figure 2.4).

*1994:* Counts from the sticky cards showed a large peak around 29 March, as the numbers of newly-emerged females in flight increased (Figure 2.5). The second major peak no doubt corresponds to the emergence of the first generation, which appeared to begin around May 9. Smaller peaks in April were probably associated with increases in temperature. Sticky cards were monitored over a longer period in 1994, and it appears that numbers within wild areas (at least by orchard A) are low during the summer, peaking again later in the fall, and dropping off by November. The fall peak is probably the result of sagebrush bloom, which provided hundreds of tiny yellow flowers in which WFT was found in high numbers (pers. obs.). Sampling of sticky cards was terminated in wild areas adjacent to orchard B over the summer because rattlesnakes were present.

**Distribution & Abundance.** In 1993, bud sampling began on 7 April as orchards were all at the silver tip stage and the trees were beginning to come out of dormancy. Southern orchards developed at different rates with A the most advanced and H the least advanced. Bloom began around 23 April in orchard A, and this orchard reached full bloom on 26 April. Mid-full bloom occurred around 30 April for the other southern orchards and about 1 May for the northern orchards (I and J). Petal fall began on 3 May



**Figure 2.4** Catches of WFT on sticky cards located in wild land adjacent to orchards A and B and concomitant mean daily air temperatures in Keremeos (°C). Count data are mean no. WFT caught per card per day from a total of 16 cards (eight posts \* two orientations (In and Out)) for both A and B from between 7 April and 1 June 1993.



**Figure 2.5** Catches of WFT on sticky cards located in wild land adjacent to orchards A and B and concomitant mean daily air temperatures in Keremeos (°C). Data are mean no. WFT caught per card per day from a total of eight cards (four posts \* two orientations (In and Out)) for both A and B from between 23 March and 20 November 1994.



in orchard A, around 5 May for the other southern orchards and 10 May for the northern orchards.

In 1994, bud sampling began on 28 March at which time buds were beginning to come out of dormancy. Again, different orchards developed at different rates with orchard A, the most advanced of the southern orchards and orchard H the least advanced. Bloom occurred earlier than in 1993 in all orchards, and bud development was particularly rapid in orchard A. Bloom occurred around 2-9 April for the southern orchards, and between 15-20 April for the northern orchards. Petal fall began between 8 April (orchard A) and 12 April (orchard H) for the southern, and 21 April for the northern orchards.

Temperatures were cooler over the period of bud development in 1993 than 1994, and thus the period during which WFT are believed to lay eggs within buds (pc to bloom) was generally longer in 1993 than in 1994, at least for the southern orchards (Figures 2.4 & 2.5 & Table 2.2).

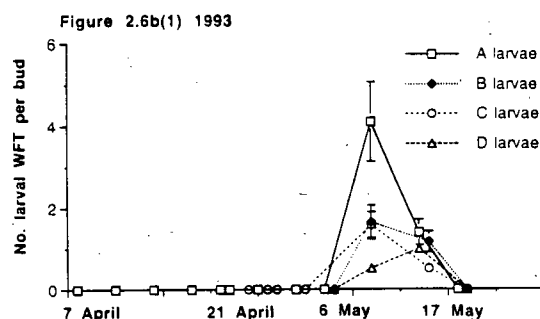
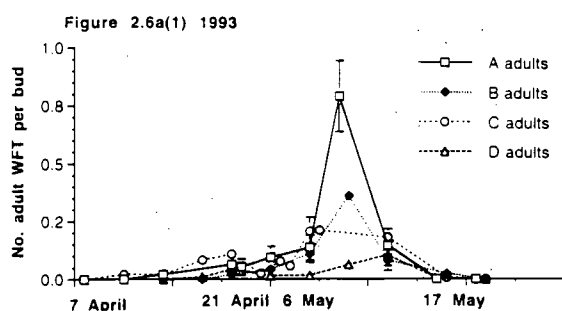
**Table 2.2** Total number of days between the 'pink colour' and 100% bloom stages in the study orchards for 1993 and 1994.

| Orchard | 1993 | 1994 |
|---------|------|------|
| A       | 24   | 7    |
| B       | 21   | 11   |
| C       | 18   | 12   |
| D       | 17   | 13   |
| E       | 17   | 13   |
| F       | 17   | 13   |
| H       | 15   | 14   |
| I       | 15   | 18   |
| J       | 14   | 18   |

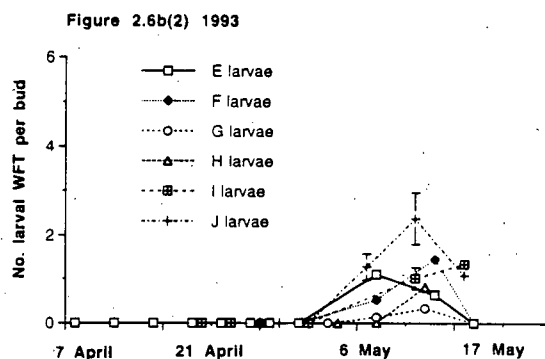
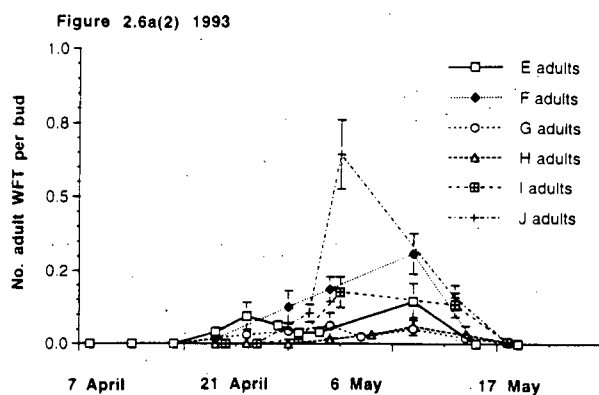
*Pesticide applications.* A variety of pesticide applications were carried out over the two years in the different orchards. In 1993, orchard A received a spray of Thiodan (endosulfan) plus dormant oil on 4 April (buds dormant) and Diazinon on 21 April (buds at the pink stage), whereas orchards B, C, D and F were sprayed with Diazinon at varying stages of petal fall (8, 9, 14 & 14 May, respectively). In 1994, orchard A was sprayed with Thiodan plus dormant oil on both 30 March (pink stage) and 27 April (petal fall). Orchards I and J received a spray of Thiodan and dormant oil on April 13 at the early/full pink stage in 1994. Orchard F was sprayed with a Thiodan plus Guthion (azinophosmethyl) mix on 23 April and orchard B received a spray of Thiodan only on 26 April when both orchards were at the late petal fall stage in 1994.

*Life Cycle.* Female adult WFT were noted on buds starting on 11 April in 1993 and 28 March in 1994 (Figures 2.6a, 2.7a). These females were not found within buds until the latter reached the early pink stage, as described above. However, WFT were clearly present on trees while the buds were still dormant. The numbers of adults remained low throughout tree development, at mean densities of less than 0.8 per bud in 1993 and less than 1 per bud in 1994. Although counts of adult WFT among orchards were more variable in 1994 than 1993, there did appear to be pronounced peaks in density during both years. In 1993, peaks in adult numbers occurred around 22/23 April in several orchards and 1-4 May in all orchards, coincident with full pink and bloom states, respectively. In 1994, peaks in adult numbers occurred in early April in a few orchards coincident with full pink and around 12-15 April in all orchards at late bloom.

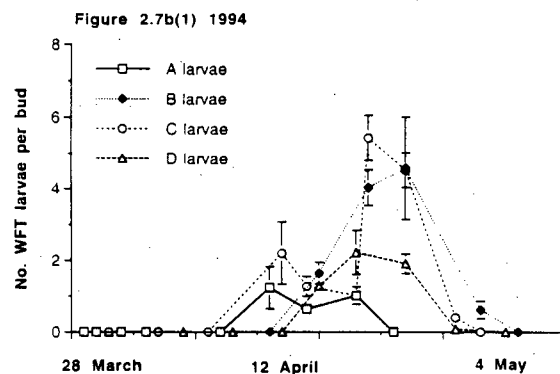
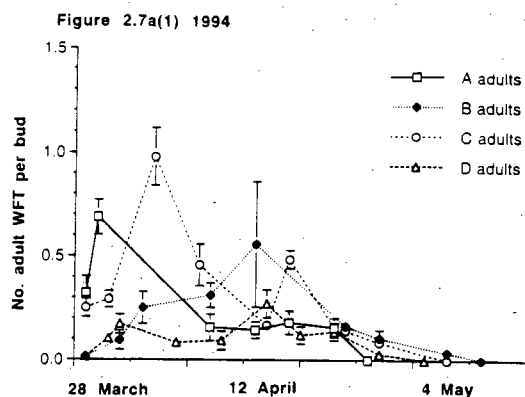
In 1993 and 1994, first instar larvae appeared in the flowers at the beginning of May, and during mid-April, respectively, which coincided with the start of petal fall (Figures 2.6b, 2.7b). The first sign of first instar larvae was on 8 May for the southern orchards, with the second instars counted on 12/13 May, whereas these dates were 12 and 17 May, respectively for the northern orchards in 1993, and in 1994, larvae first appeared around April 12 for the southern, and April 21 for the northern orchards.



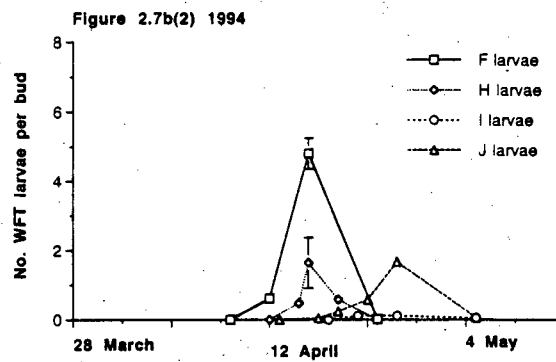
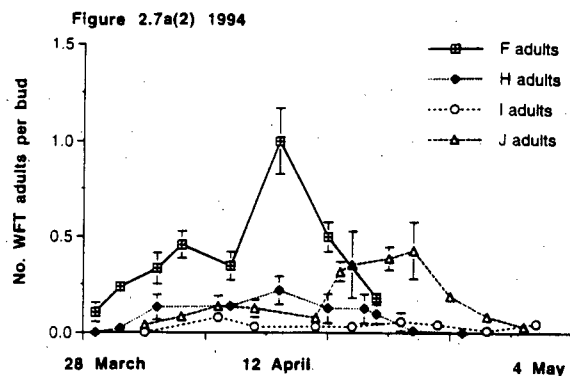
**Figure 2.6a,b (1)** Numbers of a) adult WFT and b) larval WFT per bud in orchards A, B, C, & D from 7 April - 18 May 1993.



**Figure 2.6a,b (2)** Numbers of a) adult WFT and b) larval WFT per bud in orchards E - J from 7 April - 18 May 1993.



**Figure 2.7a,b (1)** Numbers of a) adult WFT and b) larval WFT per bud in orchards A, B, C, & D from 28 March - 18 May 1994.



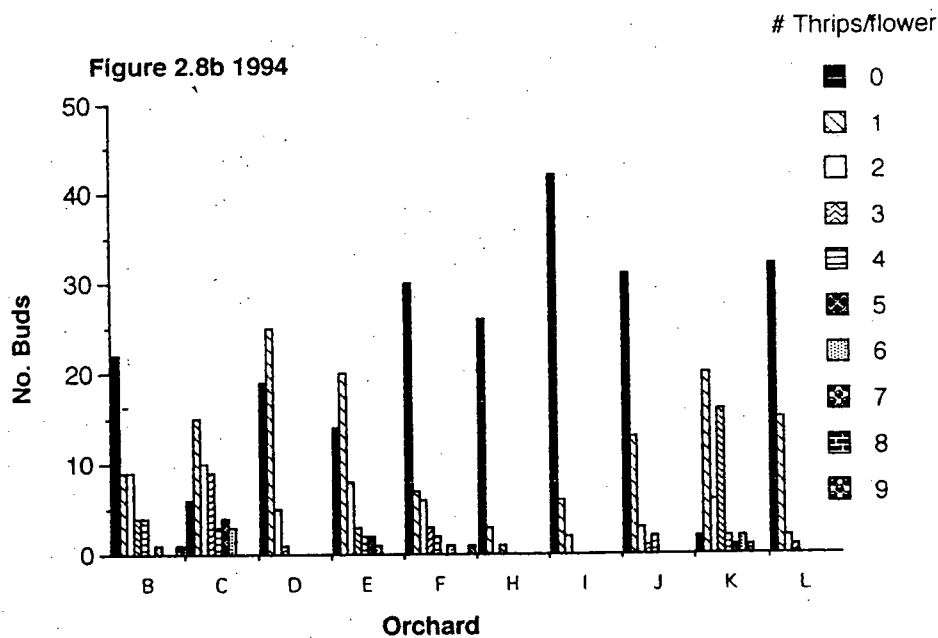
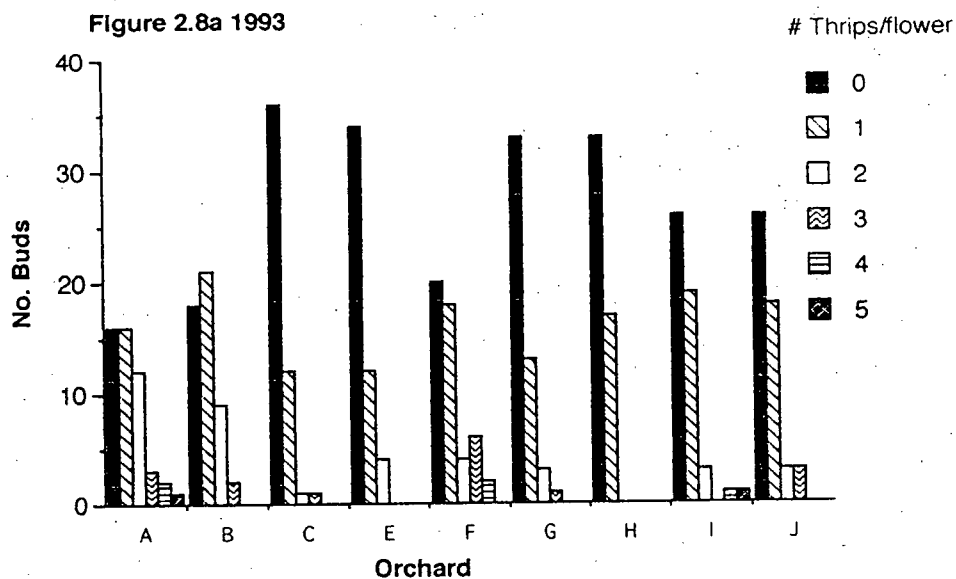
**Figure 2.7a,b (2)** Numbers of a) adult WFT and b) larval WFT per bud in orchards F, H, I & J from 28 March - 18 May 1994.

Field and laboratory examinations of buds showed that the larvae were transparent upon hatching and over 85% of them were found crawling around the filament parts of the stamens (Table 2.3). At this time, not more than 3% of the minute first instars were found around more damaging positions such as on the ovary. However, as the larvae grew, they became a creamy white/green colour from ingesting plant tissue, and were generally found lower in the husk, either attached to the developing fruit or to the hypanthium (floral cup).

**Table 2.3** Proportion of larvae attached to the filaments, ovary or hypanthium of nectarine buds. Between fifty and one hundred buds were sampled per orchard.

| <b>Orchard</b> | <b>Bud Stage</b> | <b>Filament</b> | <b>Ovary</b> | <b>Hypanthium</b> | <b>No. of larvae</b> |
|----------------|------------------|-----------------|--------------|-------------------|----------------------|
| <b>B</b>       | 5% petal fall    | 1.00            | 0.00         | 0.00              | 15                   |
| <b>C</b>       | 10% petal fall   | 0.85            | 0.03         | 0.12              | 34                   |
| <b>D</b>       | 20% petal fall   | 1.00            | 0.00         | 0.00              | 13                   |
| <b>E</b>       | 10% petal fall   | 0.94            | 0.00         | 0.06              | 18                   |
| <b>F</b>       | 25% petal fall   | 1.00            | 0.00         | 0.00              | 24                   |
| <b>B</b>       | 40% petal fall   | 0.92            | 0.08         | 0.00              | 13                   |
| <b>D</b>       | 70% petal fall   | 0.63            | 0.19         | 0.19              | 16                   |
| <b>F</b>       | 100% petal fall  | 0.29            | 0.62         | 0.09              | 55                   |
| <b>K</b>       | 100% petal fall  | 0.09            | 0.56         | 0.35              | 34                   |
| <b>B</b>       | 10% husk dry     | 0.00            | 0.89         | 0.11              | 28                   |
| <b>C</b>       | 100% husk dry    | 0.00            | 1.00         | 0.00              | 25                   |
| <b>E</b>       | 50% husk dry     | 0.00            | 0.89         | 0.11              | 36                   |

Using field examinations of buds we determined that in 1993 there were between zero and 5 larvae in a flower, with a mode of one, whereas in 1994, with the inclusion of more orchards into the study, some with very high damage levels, there were between zero and 9 larvae per flower, also with a mode of 1 (Figures 2.8a,b). Since all larvae collected



**Figure 2.8a,b** a) Frequency of 0-5 larval WFT per nectarine bud from on-site examinations of 50 nectarine buds in orchards A-J during the petal fall stage in 1993. b) Frequency of 0-9 larval WFT per nectarine bud from on-site examinations of 50 nectarine buds in orchards B-F and H-L during the petal fall stage in 1994.

from buds in both years and reared through to adults (see results for "Thrips association with fruit damage" ) were WFT, we assumed that these larval samples also were all WFT.

During 1994, the density of adults and larvae per bud was monitored almost daily on four of the sample trees in orchard E (Figure 2.9). Adults peaked on 7 April, when the buds were at about 20% full pink. Larvae appeared in buds while the trees were still at late bloom and petal fall had barely begun (50% late bloom, 5% petal fall). Larvae gradually increased in numbers, reaching a peak on 25 April, and dropping off extremely rapidly after this date until husk fall on 6 May. After husk fall, there were no larvae present on the fruit surface. It is clear that the larvae were present over quite a number of days, in this case 21 days. However, abundance was so low initially that it is unlikely that larvae would have been detected in the field situation until 19 April.

In 1993, the second instars dropped to the ground from mid-May onwards. There, they developed through the propupal and pupal stages into adults. Mean densities  $\pm$  standard errors of larvae falling to the ground were  $76/\text{m}^2 \pm 11.1$  in orchard A and  $25/\text{m}^2 \pm 5.2$  in orchard H. Of the orchards examined in 1993, orchard A had the most fruit damage, whereas fruit in orchard H had the lowest (Pearsall, chapter 3). This resulted in a mean  $\pm$  SEM of  $801 \pm 183$ , and  $444 \pm 93$  larvae falling per tree in orchard A and H, respectively. Data were not available for orchard B since mowing had occurred in this orchard before the traps could be retrieved and thus any trapped larvae were obscured by grass cuttings.

The new adult generation emerged around 21 May in 1993, and around 9 May in 1994, as indicated by huge increases in thrips densities on sticky cards placed within orchards (see below). Thus, in 1993, the time from first larval appearance (around 8 May) and the time of emergence of the new adult generation was only about 13 days whereas, in 1994, the larvae were first seen in buds from 12 April and thus development from larva to adult occurred over 27 days. This first generation was made up of a mixture of male and female WFT, unlike the overwintering generation, which was comprised of females only. Western flower thrips of the first (and further) generations were found on a variety of

Figure 2.9

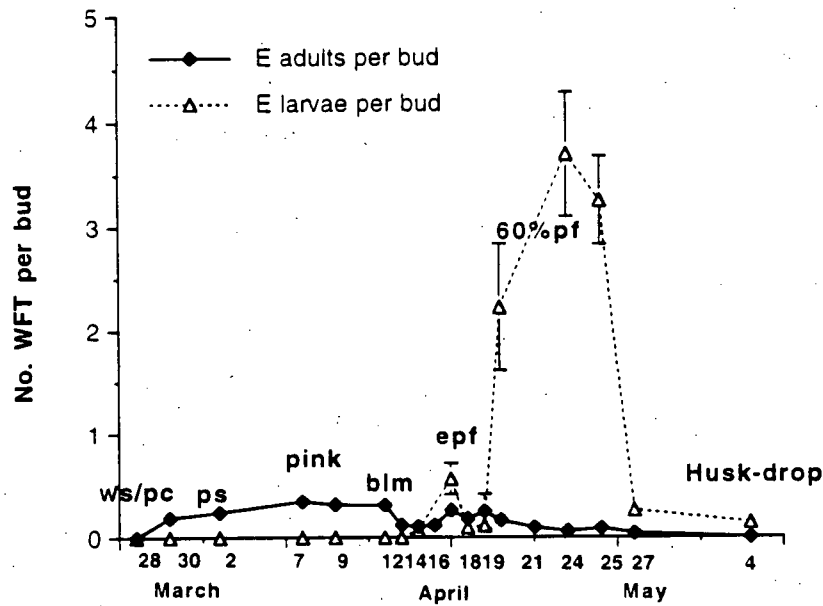


Figure 2.9 Intensive sampling of nectarine buds in orchard E for adult and larval WFT from 28 March - 4 May 1994.

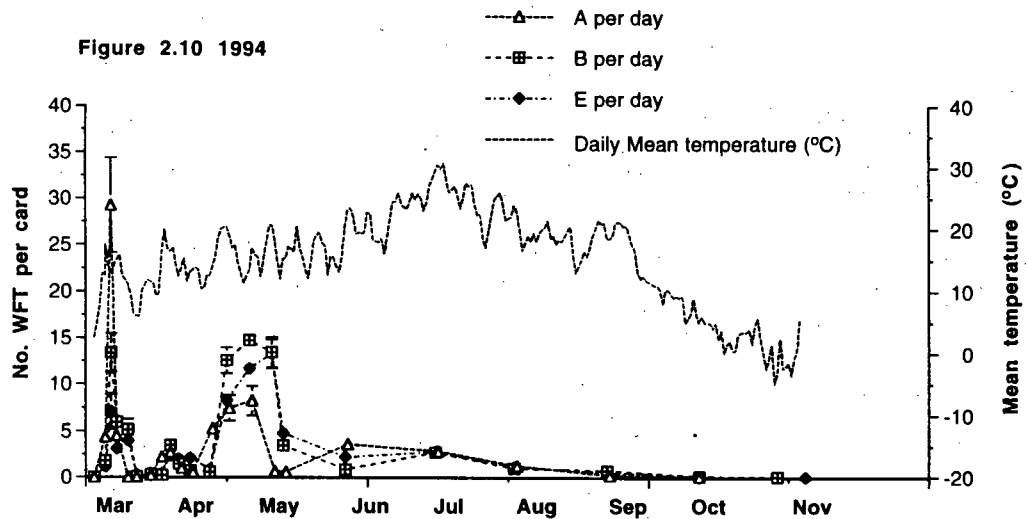


Figure 2.10 Number of WFT caught per day per card from sticky cards located on short posts (n=8 cards) within orchards A, B & E from March 23- 20 November 1994.



flowering weeds and wildflowers around and within the orchards. Between 21 and 23 May 1993, low numbers of male and female WFT also were found on nectarine leaf clusters. A few of these adult thrips laid eggs on young nectarine leaf tissue (~ 6% of leaves had larvae feeding on them by 29 May). Thrips were seen on fruit close to harvest time in August, but growers did not report any damage in the form of silvering at that time.

*Flight in orchards. 1994:* Patterns on the orchard sticky cards were very similar to those seen on the wild sticky cards for the same dates, with a clear peak in late March/early April at the time of emergence of the overwintering generation and a second large peak at emergence of the first generation in May (Figure 2.10). WFT populations were at higher levels during the summer in orchards than in wild areas, but did not exhibit the same peak in the fall as was seen in wild land. The former is no doubt the result of orchard irrigation, which allowed for lush vegetation within orchards at a time of year when vegetation elsewhere is generally highly desiccated.

*Ground cover.* All orchards studied had a ground cover of orchard grass (*Dactylis glomerata* L.) with various wildflowers and weed species occurring over the season. Orchard B had a particularly dense mat of dandelions (*Taraxacum officinale* Weber) in the spring and early summer. WFT were found within all wild flower, weed and flowering plant species sampled, both within and bordering orchards, namely: dandelion, alfalfa (*Medicago sativa* L.), Menzie's campion (*Silene cucubalus* Wibel), red clover (*Trifolium pratense* L.), white clover (*Trifolium repens* L.), black mustard (*Brassica nigra* (L.)), blue mustard (*Chorispora tenella* (Pallas)), chickweed (*Stellaria media* (L.)), Canada goldenrod (*Solidago canadensis* L.), common groundsel (*Senecio vulgaris* L.), shepherd's purse (*Capsella bursa-pastoris* (L.)), fireweed (*Epilobium angustifolium* L.), wild rose (*Rosa nutkana* K. Presl), big sagebrush (*Artemisia tridentata* Nutt.), yellow sweet clover (*Melilotus officinalis* (L.)), white sweet clover (*Melilotus alba* Medikus), hairy vetch (*Vicia villosa* Roth), pennycress (*Thlaspi arvense* L.) and saskatoon (*Amelanchier cusickii* Fern.), except for in yellow salsify (*Tragopogon dubius* Scop.). Densities of WFT per bloom are

shown for the collections taken during June 1994 only (Table 2.4). The greatest diversity of ground cover species and highest densities of WFT were seen during that month (Table 2.5). Clover and alfalfa appeared to support the largest densities of WFT throughout the season. Larvae were found within blooms of wild rose, dandelion, alfalfa, shepherd's purse, groundsel and clover which suggests that a number of the ground cover species were appropriate oviposition sites.

**Table 2.4** Densities of WFT per bloom for ground cover species available in orchard B and J during the month of June, 1994. For shepherd's purse, black mustard and sweet white clover, the number of WFT are expressed per stem (a collection of tiny flowers) and for alfalfa, per flower head (an inflorescence of tiny flowers) for a total of 36 stems and flower heads, respectively. For all other species, density of WFT is assessed per bloom from 36 flowers. Species are listed in the order of abundance in which they were present in each orchard.

| Orchard | Flower Species      | WFT per flower head | SE   |
|---------|---------------------|---------------------|------|
| B       | White clover        | 0.96                | 0.21 |
| B       | Red clover          | 11.21               | 0.23 |
| B       | Dandelion           | 1.07                | 0.21 |
| B       | Black mustard       | 1.36                | 0.15 |
| B       | White sweet clover  | 0.31                | 0.15 |
| B       | Purple alfalfa      | 1.78                | 0.28 |
| J       | White clover        | 3.59                | 1.59 |
| J       | Red clover          | 1.46                | 0.47 |
| J       | Menzie's campion    | 0.58                | 0.22 |
| J       | Dark purple alfalfa | 1.05                | 0.28 |
| J       | Pale purple alfalfa | 5.3                 | 1.63 |
| J       | Shepherd's Purse    | 0.61                | 0.15 |
| J       | Vetch               | 0.67                | 0.5  |
| J       | Common groundsel    | 0.61                | 0.15 |
| J       | Sweet white clover  | 0.39                | 0.14 |
| J       | Yellow Salsify      | 0                   | 0    |

**Table 2.5** Numbers of flowering ground cover species recorded in orchards B and J throughout the growing season. Only those plants that were commonly available (>36 blooms) throughout the orchards are included.

| Month | Number of flowering species |           |
|-------|-----------------------------|-----------|
|       | Orchard B                   | Orchard J |
| April | 1                           | 1         |
| May   | 3                           | 5         |
| June  | 6                           | 12        |
| July  | 7                           |           |
| Aug   | 5                           | 5         |
| Sept  | 5                           | 5         |
| Oct   | 3                           | 3         |

*Comparison of density estimates from bud sampling and sticky cards . Bud sampling 1993:* Mean numbers of adult and larval thrips caught per sampling date over the whole period of bud development (ws to bloom) varied significantly among orchards (Kruskal-Wallis: KW= 49.855, df=9, P=0.000 for adults; KW=39.625, df=9, P=0.000 for larvae). Peak densities of larvae per bud were significantly higher in orchards A, followed by J, C and B, than in all other orchards, with lowest densities in orchards D, H and G. Adult densities were higher in orchard J than in all other orchards. Lowest densities were found in orchards D and H. Orchards K and L were not sampled in 1993 and thus are excluded from analysis.

There were no differences among orchards in the densities of adult WFT per pink stage bud (KW=9.468, df=7, P=0.221). However, there were significant differences among orchards in the density of WFT per bud for the bloom stage (KW=19.66, df=7, P=0.006), with the highest densities in orchard J and lowest in D, I and H.

*Bud sampling 1994:* Both the densities of adult and larval thrips caught per sampling date over the period of bud development again varied significantly among

orchards (Kruskal-Wallis: KW=23.607, df=10, P=0.000 for larvae; KW= 54.682, df=8, P=0.000 for adults). Highest densities of adults were found in orchard A, followed by C, F, E and B, with lowest levels in J, D, H and I. Orchards K and L were excluded from this analysis due to more irregular sampling of adults in these orchards, such that comparisons could not easily be made. Larval densities were highest in orchards K, C, B, F and E, followed by orchards L, D, A, with lowest levels in orchards H, I and J.

Comparison of the densities of WFT caught per bud in each of the full pink and bloom stages among orchards showed that there were significant differences among orchards for both developmental stages ( $\sqrt{x+1}$  transformed data for pink stage: F=19.483, df=8,64, P=0.000; for bloom stage: KW=28.465, df=8, P=0.000). The highest densities of adult WFT per pink bud were found in orchards C and A, with lowest densities in orchards D and I. Highest densities of WFT per bloom were found in orchards C and B, followed by F, E, D, A, J, with lowest densities in orchards H and I. The discrepancy between the high densities of WFT at pink and low densities at bloom in orchard A is no doubt the result of an insecticide spray of Thiodan which was carried out between the two stages.

When comparisons of the density of WFT per pink and bloom buds were carried out between the two years for each orchard separately, it was apparent that densities of WFT were higher for each of these bud developmental stages in 1994 for orchards B, C, D, E, and H (Table 2.6). Densities at pink did not differ significantly over the two years for orchards D and J, and although WFT per pink bud were higher in 1994 in orchard A, the bloom count was lower in 1994, probably for the reason cited above. The same pattern, with a higher count at pink but lower count at bloom in 1994, also was seen in orchard I, although the former comparison was not statistically significant. This orchard, similarly to orchard A, received an insecticide application of Thiodan between these two sample dates.

**Table 2.6** Statistics for comparisons of the densities of WFT per bud at each of the pink and bloom stages for the two years of study, 1993 & 1994 using paired t-tests for orchards A-H and Independent t-tests for orchards I and J.

| Orchard | Pink 93 * Pink 94 |       |       | Bloom 93 * 94 |       |       |
|---------|-------------------|-------|-------|---------------|-------|-------|
|         | T                 | df    | P     | T             | df    | P     |
| A       | -6.334            | 7     | 0.000 | 3.705         | 7     | 0.008 |
| B       | -3.581            | 7     | 0.009 | -2.558        | 7     | 0.038 |
| C       | -6.881            | 7     | 0.000 | -3.145        | 7     | 0.011 |
| D       | -1.587            | 7     | 0.156 | -4.025        | 6     | 0.007 |
| E       | -3.124            | 7     | 0.017 | -4.447        | 7     | 0.003 |
| F       | -2.172            | 5     | 0.042 | -3.766        | 5     | 0.013 |
| H       | -----             | ----- | ----- | -2.5          | 6     | 0.047 |
| I       | -0.882            | 20    | 0.388 | 2.173         | 17    | 0.044 |
| J       | -0.277            | 25    | 0.784 | -----         | ----- | ----- |

*Wild vs. orchard sticky cards vs. bud samples 1994:* Densities of WFT on sticky cards in the spring showed similar patterns in wild areas and orchards, although peaks were higher in wild areas. During the summer, densities were higher in the orchards but higher in wild areas in the fall. Densities of WFT caught on sticky cards located within orchards A and B were much greater than the densities of adult WFT found in bud samples in 1994. Nectarine blooms did not appear to house much more than one WFT per bud at any time during development. In orchard A, there were synchronous peaks at the time of bloom in the densities of WFT on sticky cards and in buds. In orchard B, buds developed more slowly such that the spring peak of flight occurred prior to the buds reaching the bloom stage at which time densities of WFT peaked in buds.

*Ground cover vs. sticky cards 1994:* Abundance of WFT on clover and dandelion could be compared with sticky card catches since these blooms were present throughout most of the growing season. The densities of WFT on clover from within orchards B and

J showed similar patterns to the catches of WFT on sticky cards from orchard B, with high densities in June, low densities over the summer, and slightly higher densities in the fall, except that in orchard B, WFT densities peaked on dandelion and red clover on 8 August (Figure 2.11). This peak may be the result of increased densities of WFT within this orchard which was well irrigated at this time just prior to harvest.

*Species.* The only species of thrips found within nectarine blossoms were: *F. occidentalis* (pale and dark forms), a new species of thrips, *Thrips fallaciosus* Nakahara and *Haplothrips kurdjumovi* Karny. The latter, although predatory, is not known to feed on WFT. On all dates, western flower thrips were the most abundant species found within blossoms. Apart from aphids, there were very few other species of insects present on the trees at the time that the adult females were laying eggs.

These three species were also the most common species of thrips captured on sticky cards during the period of nectarine flower development. The other most commonly captured thrips species found flying into orchards were: *Thrips treherni* Priesner, *Frankliniella fusca* (Hinds), *F. minuta* (Moulton), *T. tabaci* Lindeman, *Aeolothrips fasciatus* (Linnaeus), *T. vulgatissimus* Haliday, *Odontothrips loti* (Haliday), *Haplothrips verbasci* (Osborn), *H. halophilus* Hood, *Neohydatothrips* sp. and various *Aeolothrips* spp, but none of these were found within nectarine blossoms. Of these species, only the *Haplothrips* spp. and the *Aeolothrips* spp. are predacious. The other species are phytophagous and belong in the family Thripidae. The *Haplothrips* spp. belong in the family Phlaeothripidae.

Figure 2.11a

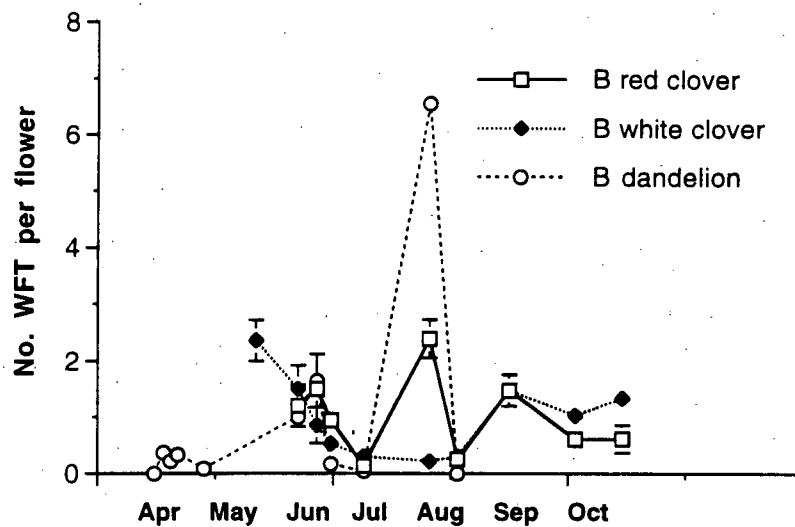
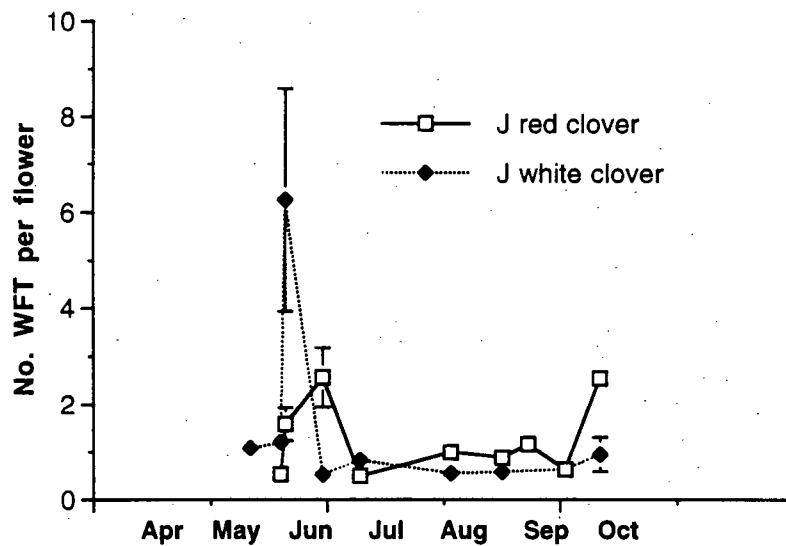


Figure 2.11b



**Figure 2.11a,b** Number of WFT per flower head for a) samples of dandelion, red clover and white clover taken from the ground cover of orchard B from April - October 1994; and b) samples of red clover and white clover taken from the ground cover of orchard J from May - October 1994.

*Damage Assessment.* In both years, fruit damage was visible at husk-fall, which occurred around the end of May in 1993 and around the end of April in 1994. The russetting of fruit, attributable to thrips, was clearly visible when the fruit was only about 1 cm long.

Paired comparisons of the mean damage per tree occurring in each orchard for 1993 and 1994 illustrated that there were significantly greater damage levels in 1993 than 1994 in orchards A, H, I and J, and greater damage levels in 1994 than 1993 in orchards C, D, and E (paired t-test, all  $P < 0.05$ ) (Table 2.7). There was no difference in damage between years in orchards B or F (paired t-test, both  $P > 0.05$ ). In all cases except orchard H, there were higher densities of larvae in the year coincident with most damage. In both years, damage levels varied significantly among orchards (ANOVA, 1993:  $F=10.829$ ,  $df=8/65$ ,  $P=0.000$ ; 1994:  $F=41.153$ ,  $df=8,65$ ,  $P=0.000$ ). In 1993, damage levels were greatest in orchards A, followed by I, J and E, then orchards B, G, C, F, D and H. In 1994, there was significantly greater damage in orchards C, K and E, followed by orchards B and D, then L and F, followed by J, finally A, I and H. In both years, orchard H had the lowest damage levels. Orchards I, J and A showed the largest differences in damage between years, which again may be the result of the pink spray of Thiodan which was carried out in these three orchards in 1994 only.



**Table 2.7** Mean damage per tree for each orchard sampled during 1993 and 1994. SEM is given in parentheses. Sample size =15 fruit from each of eight sample trees per orchard, for orchards A-E, G, H, I, six sample trees for orchard F, and 15 sample trees for orchards J and K. Orchard L was not sampled for damage.

| Orchard | Mean damage<br>1993 | Mean damage<br>1994 | T     | df    | P     |
|---------|---------------------|---------------------|-------|-------|-------|
| A       | 5.10(0.25)          | 2.14(0.13)          | 10.18 | 7     | 0.000 |
| B       | 3.56(0.24)          | 4.17(0.35)          | 1.269 | 7     | 0.245 |
| C       | 3.28(0.25)          | 6.44(0.19)          | 9.869 | 7     | 0.000 |
| D       | 2.80(0.20)          | 3.93(0.24)          | 4.703 | 6     | 0.003 |
| E       | 3.90(0.29)          | 5.67(0.31)          | 4.922 | 7     | 0.002 |
| F       | 3.07(0.30)          | 2.90(0.13)          | 0.295 | 5     | 0.78  |
| G       | 3.53(0.38)          | N/A                 | ----- | ----- | ----- |
| H       | 2.67(0.11)          | 1.66(0.16)          | 6.063 | 6     | 0.001 |
| I       | 4.17(0.36)          | 1.81(0.25)          | 4.844 | 7     | 0.002 |
| J       | 4.52(0.29)          | 2.83(0.29)          | 3.779 | 11    | 0.003 |
| K       | N/A                 | 6.30(0.21)          | ----- | ----- | ----- |

*Analyses of factors affecting abundance.* In 1993, there were no apparent relationships between density of adult thrips, density of larval thrips (from the early or late counts) or fruit damage with the position of a tree within the orchard ( $P>0.1$ ) (Table 2.8).

**Table 2.8** Density of adult and larval WFT per tree and associated mean damage per tree for each of five within-orchard locations for orchards C, I and J. Data are means per tree for a total of 12 bud samples per tree (for WFT counts) and 15 fruit per tree (for damage assessments) for a total of three trees per location, with the associated standard errors given in parentheses.

| Orchard | Location | Adults      | Peak Larvae  | Damage     |
|---------|----------|-------------|--------------|------------|
| C       | Side 1   | 1.92(0.58)  | 18.33(10.84) | 3.67(0.62) |
| C       | Side 2   | 3.08(1.54)  | 21.33(8.09)  | 3.4(0.62)  |
| C       | Side 3   | 1.88(1.32)  | 28.33(5.82)  | 3.11(0.06) |
| C       | Side 4   | 2.58(0.80)  | 4.67(2.19)   | 3.05(0.16) |
| C       | Inside   | 2.67(0.88)  | 22.67(9.67)  | 3.02(0.43) |
| I       | Side 1   | 4.83(2.89)  | 19.67(2.6)   | 5.13(0.69) |
| I       | Side 2   | 3.17(1.69)  | 17.67(3.18)  | 4.73(0.37) |
| I       | Side 3   | 1.00(0.58)  | 17.67(3.18)  | 4.89(0.51) |
| I       | Side 4   | 2.33(1.33)  | 16.67(3.18)  | 4.17(0.95) |
| I       | Inside   | 1.33(0.88)  | 12.67(1.2)   | 3.73(0.58) |
| J       | Side 1   | 7.00(0.99)  | 21(6.08)     | 4.13(0.29) |
| J       | Side 2   | 9.67(1.67)  | 29(0.66)     | 5.9(0.36)  |
| J       | Side 3   | 7.33(0.33)  | 50.00(13.43) | 3.99(0.51) |
| J       | Side 4   | 10.00(7.02) | 35.00(18.62) | 5.34(0.46) |
| J       | Inside   | 9.33(3.84)  | 16.00(2.31)  | 3.88(0.32) |

In 1993, the numbers of thrips per nectarine bud were too low to enable statistical comparisons to detect any differences in the densities of thrips with position within a tree. However, there appeared to be no particular relationship between density of thrips and location within a tree.

In 1994 there were no significant effects of position within a tree and the density of either adults or larvae for orchards C and E, except in the case of adults in orchard C, where we found more adults up than down (Tables 2.9a,b).

**Table 2.9a** Pooled densities of WFT per 16 blooms per tree for several paired comparisons of location within a tree (In versus Out and Up versus Down). Each paired comparison was between eight trees, thus  $df=7$  in all cases. Data were collected in 1994.

| Orchard | Date     | Stage  | IN                | OUT               | T      | P     | UP               | DOWN              | T     | P     |
|---------|----------|--------|-------------------|-------------------|--------|-------|------------------|-------------------|-------|-------|
| C       | 9 April  | Adult  | 3.25<br>(0.82)    | 3.15<br>(1.02)    | -0.277 | 0.79  | 3.00<br>(0.70)   | 1.75<br>(0.50)    | 3.989 | 0.005 |
| E       | 9 April  | Adult  | 6.75<br>(1.10)    | 6.25<br>(1.22)    | 0.509  | 0.626 | 5.75<br>(0.82)   | 6.25<br>(0.82)    | 1.528 | 0.17  |
| C       | 20 April | Larval | 137.38<br>(16.32) | 146.63<br>(22.87) | -0.928 | 0.384 | 143.5<br>(15.02) | 117.89<br>(10.36) | 1.35  | 0.219 |
| E       | 20 April | Larval | 44.13<br>(9.02)   | 42.88<br>(8.63)   | 0.333  | 0.749 | 31.75<br>(6.26)  | 30.50<br>(6.43)   | 0.437 | 0.675 |

**Table 2.9b** Comparison of larval density for each of four different within-tree locations (Up-In, Up-Out, Down-In, Down-Out) for orchard C. Comparisons were made among four eight sample trees. Values given are pooled densities of WFT per 12 blooms for each location with the associated standard error given in parentheses. ANOVA statistics for  $(x+0.5)^2$  transformed data:  $F=0.536$ ,  $df=3,28$ ,  $P=0.661$ . Data were collected in 1994.

| Orchard | Date     | Stage  | UP              |                 | DOWN            |                 |
|---------|----------|--------|-----------------|-----------------|-----------------|-----------------|
|         |          |        | IN              | OUT             | IN              | OUT             |
| C       | 15 April | Larval | 11.75<br>(2.60) | 19.00<br>(4.74) | 14.50<br>(2.51) | 15.63<br>(4.00) |

In 1993 numbers of adult WFT per nectarine bloom did not differ significantly from the numbers per nectarine bud at the full pink stage in orchard C (paired t-test,  $P>0.05$ ) (Table 2.10a).

In 1994 the abundance of adult WFT per bud was compared for several different bud developmental stages: Densities of WFT were equally low between white swell and pink colour and also between pink colour and early petal show bud stages; for comparisons of full pink versus bloom stages, the abundances of WFT per bud did not vary significantly among buds ( $p>0.1$  for orchards E and K) except for in orchard C, where there were significantly greater numbers of WFT per bud in the bloom than the pink stage; for pink colour versus pink and early petal show versus pink there were significantly greater numbers of adult WFT per bud in the pink stages for all orchards tested ( $P<0.05$  for orchards C, F and K) (Table 2.10a). Number of WFT per bud did not vary significantly with bloom stage among the early bloom, mid-bloom and late -bloom stages in orchards B, E or F (Table 2.10b). Finally, numbers of WFT per bloom bud were higher than per petal fall bud in orchard E (Table 2.10a).

**Table 2.10a** Comparison of WFT densities among buds of different developmental stages. WFT per tree(1) and WFT per tree(2) give the density of WFT for the first life stage and second life stage for each paired comparison. Densities are expressed on a per tree basis (for a total of n buds per tree) with associated standard errors in parentheses. Developmental stages are defined in Methods. Statistics given are for 7 degrees of freedom, in each case.

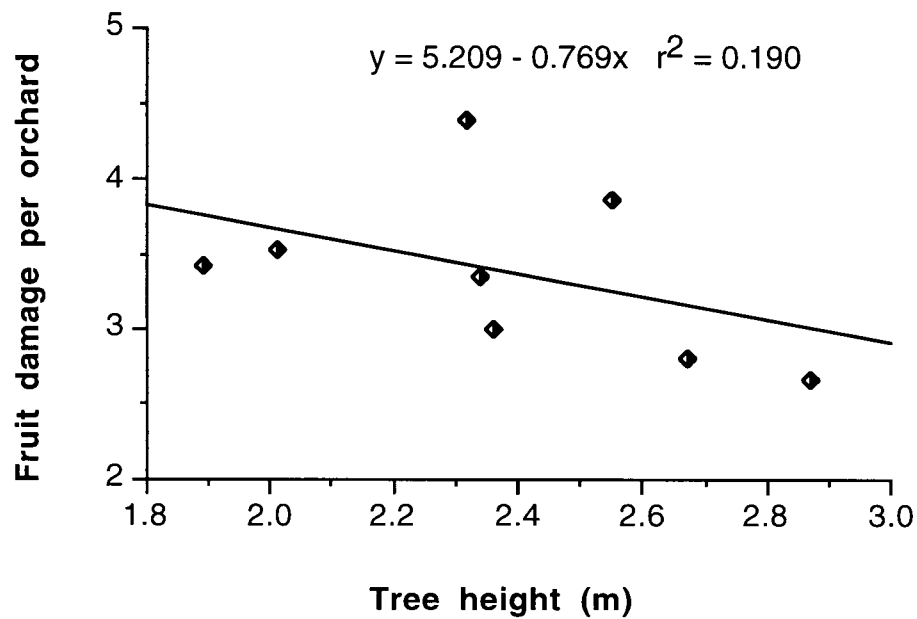
| Year | Orch | Bud stages compared  | WFT/tree stage (1) | WFT/tree stage (2) | Buds /tree | T     | P     |
|------|------|----------------------|--------------------|--------------------|------------|-------|-------|
| 1994 | C    | pc vs. pink          | 1.63(0.46)         | 11.75(1.67)        | 12         | 6.43  | 0.000 |
| 1994 | E    | pc vs. pink          | 0.25(0.26)         | 2.875(0.69)        | 12         | 3.121 | 0.017 |
| 1994 | K    | eps vs. pink         | 0.98(0.52)         | 4.13(0.95)         | 12         | 3.418 | 0.016 |
| 1993 | C    | pink vs. bloom       | 0.63(0.26)         | 1.75(0.70)         | 12         | -1.35 | 0.219 |
| 1994 | C    | pink vs. bloom       | 3.75(0.98)         | 5.5(1.18)          | 12         | 2.701 | 0.031 |
| 1994 | E    | pink vs. bloom       | 4.25(1.91)         | 2.63(0.625)        | 12         | 1.297 | 0.236 |
| 1994 | K    | pink vs. bloom       | 6.00(1.23)         | 4.00(0.96)         | 12         | 1.74  | 0.231 |
| 1994 | E    | bloom vs. petal fall | 4.38(0.84)         | 1.63(0.57)         | 12         | 2.366 | 0.05  |

**Table 2.10b** Numbers of adult WFT per bud for each of three bloom stages: early, mid and late bloom in orchards B, E and F in 1994. Statistics given are for 2,21 degrees of freedom.

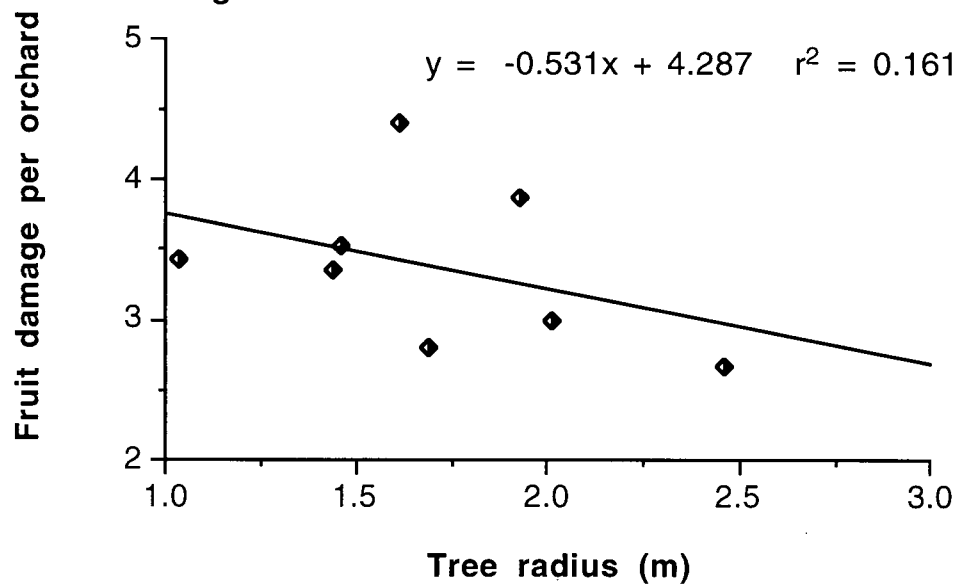
| Orchard | Early bloom | Mid-bloom  | Late-bloom | Buds /tree | F     | P     |
|---------|-------------|------------|------------|------------|-------|-------|
| B       | 7.00(1.27)  | 7(1.28)    | 11(1.91)   | 24         | 3.21  | 0.123 |
| E       | 7.75(1.41)  | 4.75(1.13) | 6.00(1.14) | 24         | 1.691 | 0.209 |
| F       | 9.00(1.07)  | 5.00(1.58) | 6.00(1.51) | 24         | 2.161 | 0.14  |

There was no significant relationship between mean fruit damage per tree and tree size in any orchard in 1993 (linear regression: for radius,  $r^2 = 0.161$ ,  $df = 1,6$ ,  $F = 1.153$ ,  $P = 0.324$ ; for height,  $r^2 = 0.19$ ,  $df = 1,6$ ,  $F = 0.74$ ,  $P = 0.423$ ). However, when the

**Figure 2.12a**



**Figure 2.12b**



**Figure 2.12a,b** Relationship between a) mean tree height per orchard (in m) and mean fruit damage per orchard in 1993; and b) mean tree radius per orchard (in m) and mean fruit damage per orchard in 1993, as assessed by linear regression.

mean damage per orchards was regressed against the mean tree height and mean tree radius, the trend was for larger trees to experience lower damage (Figures 2.12a,b).

In 1993 the abundance of thrips per bud was too low to permit statistical analysis, but in general there appeared to be no effect of time of sampling on thrips density estimates.

In 1994 in orchard A, there were significantly more thrips per bloom bud in the late afternoon than the noon count, whereas in orchard C, there were significantly fewer thrips per bud for the early morning count than either of the counts later in the day (both  $P < 0.05$ ). For orchard K, no significant differences were detected among the different times of day. Thus, consistent patterns were not detected among orchards (Table 2.11).

**Table 2.11** Comparison of the densities of adult WFT per bloom for each of three orchards, A, C, and K for three different times of day of bud collection. Numbers given are densities of WFT for a pooled sample of 12 buds per tree for a total of 12 trees per orchard, with associated standard errors given in parentheses. Data for A were  $\sqrt{(x+0.5)}$  transformed, whereas data for orchard C could not be adequately transformed.

| Orch | 0830       | 1330        | 1800        | F/KW      | df   | P     |
|------|------------|-------------|-------------|-----------|------|-------|
| A    | 5.33(0.76) | 4.58(0.73)  | 7.42(1.27)  | F=3.609   | 2,23 | 0.038 |
| C    | 7.88(1.51) | 12.83(0.85) | 13.83(1.27) | KW=14.017 | 2    | 0.001 |
| K    | 7.42(0.79) | 7.25(0.78)  | 9.33(0.88)  | F=1.997   | 2,23 | 0.152 |

Sample sizes were likely too low for us to be able to detect any differences among pruning dates. However, there appeared to be no significant difference in fruit damage, adult or peak larval density with pruning date in 1993 (all  $P > 0.1$  for orchard E), although both adult density and damage levels were lower on trees that were pruned late (Table 2.12).

**Table 2.12** Density of adult and larval WFT and associated damage per tree for each of four trees per treatment in orchard E. Standard errors are given in parentheses. Statistics given are all for six degrees of freedom.

|                            | <b>Early<br/>Pruning</b> | <b>Late<br/>Pruning</b> | <b>T</b> | <b>P</b> |
|----------------------------|--------------------------|-------------------------|----------|----------|
| <b>Adults per bud</b>      | 0.34(0.12)               | 0.29(0.09)              | 0.324    | 0.757    |
| <b>Peak larvae per bud</b> | 1.21(0.88)               | 1.37(1.10)              | -0.234   | 0.823    |
| <b>Damage</b>              | 4.24(0.54)               | 3.74(0.25)              | 0.838    | 0.434    |

**Thrips association with fruit damage.** In both years, all reared larvae developed into WFT suggesting that although there are two other species found as adults within blossoms during sampling (*T. fallaciosus* and *H. kurdjumovi*), these species do not appear to be laying eggs that develop to viable larvae within the buds, at least during the period of sampling which lasted from dormancy to after petal fall. In 1993, the pale and intermediate forms of WFT were not differentiated but described as the "pale morph". From orchard C, five larvae developed into the dark female morph of the western flower thrips, 28 into the pale female morph and seven into males. The 14 larvae that developed into adults from orchard J were all the yellow-coloured (pale morph) form of female WFT. In 1994 larvae from Orchard C developed into a total of 11 dark morph female WFT, 40 pale brown-coloured (intermediate morph) female WFT, 30 yellow-coloured (pale morph) female WFT and 15 yellow-coloured male WFT.

**Larval Movement.** No larvae of any stage were caught on the sticky bands at any of the dates sampled in all of the orchards.



## 2.4 DISCUSSION

The life cycle of western flower thrips in the Dry Central Interior, British Columbia, appears to be very similar to that of WFT in California, with adult WFT overwintering in areas of wild land and moving into nectarine orchards as the trees come into bloom (LaRue *et al.*, 1972). However, we also found that a substantial amount of emergence occurred from within orchards, not only from the ground but also from protected places in the bark of the nectarine trees. Chambers and Sites (1989) found that WFT were able to overwinter as adults both in the soil and in the epigeous plant growth of alfalfa and winter wheat on the Texas South Plains. Cranshaw (1988) found that WFT overwinters in a dormant condition in protected locations such as under leaves or in crevices in the tree bark. Felland *et al.* (1993c) recovered overwintering WFT in emergence traps placed over leaf litter, dead grass and bare soil in Pennsylvania.

Adult WFT are known to overwinter on a variety of wild host plants in Florida, Georgia, Louisiana, Pennsylvania and Texas (Newsom *et al.*, 1953; Chambers and Sites, 1989; Stewart *et al.*, 1989; Chamberlin *et al.*, 1992; Felland *et al.*, 1993a; Chellemi *et al.*, 1994), although Yonce *et al.* (1990a) did not find any WFT in a variety of weed and grass species in and near nectarine orchards over the winter in Georgia. In some areas, for example, North Carolina, WFT also may be able to overwinter in the larval form (Cho *et al.*, 1995). Chamberlin *et al.* (1992) and Buntin and Beshear (1995) suggested that WFT may reproduce on winter and spring hosts. It is highly unlikely that this occurs in the Okanagan since temperatures are not high enough over the winter season. No males of this species were collected in the spring, which would have been expected had there been any reproduction over the winter months. Indeed, overwintering appears to be carried out only by female western flower thrips. It is unclear why males are not found to overwinter as they are present in high numbers in the late fall (pers. obs). The sex ratio of the offspring produced by these emerging females in both 1993 and 1994 in laboratory studies were a

mixture of males and females (Pearsall, unpublished data). Because of the haplodiploid life history of this insect, unmated females produce only male offspring, thus our findings indicated that WFT females were probably mated before overwintering.

Information on overwintering behaviour is critical for use in pest management decision making. Emergence from the ground did not occur to any great extent until air temperatures reached a daily maximum of 10°C. Although there did appear to be distinct peaks of flight of newly emerged adults, actual emergence appeared to occur gradually over a fairly extended period of time. We found dormant WFT within both soil and leaf litter samples and it is likely that WFT overwintering in these different locations would require varying lengths of time to come out of dormancy, as it would take longer for the ground to warm up adequately as compared to the leaf litter. The lack of a notable peak for emergence thus precludes the use of strategies such as mass trapping or accurate timing of application of insecticide to coincide with emergence.

Emergence in both years began before the trees had come out of dormancy. Thus, insects are active on trees long before they are able to climb into the buds. It is even possible that temperatures may reach high enough levels during the winter to enable WFT overwintering on the bark to exhibit low levels of activity. It is likely that overwintering WFT may be more prevalent within those orchards which maintained a ground cover throughout the late summer and fall. Although there were lower numbers of WFT caught in the wild land traps as compared to the orchard traps, it is clear that the surface area of each trap is minimal in comparison with the vast tracts of wild land surrounding these orchards. The total numbers of WFT overwintering within wild land may be huge.

The sticky cards located on posts within orchards and wild areas give an abundance estimate of thrips in flight whereas the emergence traps measure the abundance of thrips emerging from overwintering places. These events (flight and emergence) may be controlled by different threshold temperatures, thus a peak in early spring of WFT numbers on the sticky cards does not necessarily signify a peak in emergence, but that temperatures

have reached levels at which the newly emerged adults are able to become airborne. However, thrips activity within orchards is not dependent upon the threshold temperatures for flight, since there is a population of insects already present in the orchards.

Early in the spring, WFT are the most commonly captured species both within blooms, ground cover species and on the yellow sticky cards. Results of the larval rearing studies suggest that WFT is the only species ovipositing in the nectarine buds at this time of year, and thus is the single species to which the russetting damage may be attributed. Adult females were found on dormant buds, but it was not until the early petal show stage that they were able to get inside of buds. Density of adults never became much higher than one per bud in either year, and was generally much lower than this. Adults were found associated only with flowers while these were present, although low numbers were found on the young leaf tissue after petal fall.

Western flower thrips were also found in nectarine blooms in Georgia, together with the flower thrips, *Frankliniella tritici* (Fitch), and the soybean thrips, *Neohydatothrips variabilis* (Beach) (Yonce *et al.*, 1990a). The relative abundance of WFT was found to vary from year to year in their study, and it was the most injurious species found, causing both russetting injury from feeding larvae and silvering injury from adult feeding near to final fruit swell. The presence of WFT also is associated with injury in nectarine orchards in California, Italy, and France (LaRue *et al.*, 1972, Bournier, 1970, Cravedi *et al.*, 1983, Cravedi and Molinari, 1984, Grasselly *et al.*, 1993). Injury to nectarines also has been found in Greece (Kourmadas *et al.*, 1982), but this was mainly attributed to *Frankliniella intonsa* (Trybom) and *Taeniothrips meridionalis* Priesner. In Pennsylvania, fruit injury is present mainly in the form of silvering (Felland *et al.*, 1993b, 1995). This is no doubt due to the fact that the emergence of WFT in this region is well synchronised with petal fall, rather than the buds coming out dormancy, and thus WFT is available too late to cause scarring damage in this region.

Hot and dry conditions are known to favour thrips development, whereas cool and rainy weather apparently hinder it (Lewis, 1973). Indeed, Watts (1936), suggested that thrips populations are influenced by rainfall more than any other natural factor. However, Yonce *et al.* (1990a) did not find any evidence to suggest that WFT populations were benefited by low rainfall. Felland *et al.* (1993a), however, suggested that higher WFT populations in Pennsylvania in 1991 than 1992 were brought about partly by the high temperatures and severe drought of 1991, rather than the cool and wet conditions of 1992. The high temperatures of 1991 in their study apparently led to rapid reproduction and the lack of rainfall to increased survival. In our study, populations were generally lower in 1993 than 1994 which may partly have been the result of the wet and cool conditions that occurred during the spring of 1993.

Changes in abundance of WFT were related to changes in crop phenology. At any one time we found highest densities of WFT in those orchards that were most developmentally advanced, with notable peaks in adults coincident with the full pink and bloom stages of the trees. WFT also appear to prefer the most developmentally advanced blooms on a tree at any one time, with the exception of the period when trees have a mixture of either pink buds and blooms or blooms and petal fall buds present. In the case of the former, we found generally equal densities in the two bud types, whereas for the latter, WFT were found to concentrate in the open blooms. Terry and DeGrandi-Hoffman (1988) similarly found that WFT appear to prefer open apple blossoms to unopened buds or blossoms without petals.

We found that both overwintering generation adults and first-generation larvae were primarily associated with nectarine buds rather than leaf tissues. Higgins (1992) found that most larvae were located on leaves whereas most adult females were associated with flowers of bell peppers and long English cucumbers. She attributed this niche separation to the temporary nature of the flowers in these crops. The flowers of nectarine are also

temporary: however, the buds provide optimal protection for the larvae, and the development of the larvae appears to be well synchronised with bud development.

We found no consistent effect of location of trees within orchards or buds within a tree on estimates of WFT density. Although we did find greater numbers of adults in upper portions of trees in orchard C, this result was neither replicated for adults in orchard E, nor for larvae in either orchard. However, the orchards used for these studies were no larger than half an acre, and the trees were generally small (less than 2m in height) as most of these plantings were fairly young (less than 5 years old). As WFT is such a mobile insect, it is not surprising that they were fairly evenly distributed within these orchards.

Many other studies of WFT in other crops have noted location effects. For example, Pickett *et al.* (1988) found that adult WFT were primarily centrally located in the cotton plant canopy. This within-plant distribution was believed to be due to the preference by this species of a habitat protected from direct sunlight and wind (Lewis, 1973). These authors found that WFT moved up the cotton plants as they grew, probably in response to abundant spider mites, which were apparently a food source, and younger leaves and flowers, which were all located higher in the canopy as the plant ages. They did find that the density of larvae, however, was highest on the lower half of plants which they suggest may have been due to the poorer coverage by insecticides at these levels.

Felland *et al.* (1993d) found highest densities of WFT on the lower part of nectarine canopies in Pennsylvania on fruit just prior to harvest. Salguero Navas *et al.* (1991a) found that adult WFT were more abundant on flowers on the upper half of tomato plants compared with flowers on the lower half of plants and that adult densities were greater near field margins. Also in accordance with our study, they found that adult WFT were rarely found in plant structures other than the flowers.

Several other studies using sticky cards to assess the relative density of WFT have shown that the greatest numbers were caught on sticky cards placed just above the crop

canopy (e.g. Brodsgaard, 1989b; Gillespie and Vernon, 1990). The latter authors suggested that most movement of WFT in a crop field occurs just above the top of the crop.

Sites *et al.* (1992) studied the interplant dispersion of WFT on onions; in late May WFT were primarily found in the basal half of leaves. However, as the season progressed, the dispersion shifted upwards to include the apical half of leaves, and in early June WFT displayed a nocturnal pattern of random dispersion, followed by an afternoon aggregation on the apical half of leaves, and then a evening descent back to random dispersion. Shipp and Zariffa (1991) found that both adult and larval WFT were most concentrated on the top one third of sweet pepper plants.

Thus, many studies have found that WFT were located in the top part of plant canopies, although there is suggestion that the use of insecticides may have an effect on distribution, at least of larvae. We studied the effect of position within a tree on adult and larval densities in two orchards that were in their first year of conversion to organic in 1994 (C & E): thus insecticide use was not a concern during the second year of this study.

Although we found no within-orchard or within-tree spatial effects, we did find clear within-bud effects. The location of larvae within buds appeared to change as the larvae grew. Upon hatching over 95% of the minute larvae were found located on the filaments and crawling around the base of the filaments, whereas as both the developing fruitlet and the larvae grew, an increasing proportion of the larvae were found either on the fruit itself or on the hypanthium. Initially, the filaments are probably the preferred location for the minute first instars as they provide the most protection and shelter for the thigmotactic larvae. As the husk and the filaments dry up, larvae are most protected under the husk. This information probably has great bearing on the choice of optimal timing for spray of insecticide. It suggests that a spray of insecticide at very early petal fall, while the larvae are highly exposed at the base of the filaments would no doubt be far more effective than one carried out once the larvae had moved further down into the area around the fruit.

We found no consistent effect of the time of day on estimates of WFT abundance. This is in contrast to the results of Yonce *et al.* (1990) who found that the best time of day to sample for thrips in nectarine was the early morning, since this is the time that they are apparently least active. However, Salguero Navas *et al.* (1991a) found that the time of day of sampling had no effect on abundance estimates of WFT on tomato. However, our study would no doubt be more robust if carried out over a number of days rather than on just one day.

We also found no effect of pruning on thrips density estimates. Lewis (1973) suggested that new growth on trees may provide extra shelter for thrips which suggests that regular pruning of trees would be beneficial. However, in our study, only half of the orchard was pruned, and again, the small size of the orchard, together with the dispersal ability of WFT, may have precluded any effect of pruning.

Only one generation occurs on the nectarine buds, but a few larvae were found on leaves later in the summer which suggests that there may be limited reproduction by further generations on the leaves of the trees. However, these later generations of thrips do not appear to be causing any damage to the nectarine crop. The bulk of reproduction in orchards after nectarine bloom is no doubt taking place on the flowers of the ground cover. All ground cover species sampled yielded adult and sometimes larval WFT throughout the summer and fall. Clover and alfalfa appeared to be the most "attractive" to WFT, which may associated with the complexity of these blooms, as compared to a simple and open flower such as yellow salsify, which contained no WFT. Felland *et al.* (1995) also found WFT in clover blooms on the orchard floor in Pennsylvanian nectarine orchards. The presence of larvae in a number of the ground cover species suggested that a number of these were appropriate oviposition sites. The population of WFT overwintering within orchards is no doubt derived in part from the ground cover blooms present in the fall. Although it would have been of great interest to monitor early spring emergence of WFT

between the rows of fruit trees, in the areas covered by ground cover blooms in the late fall, we could not leave emergence traps in these locations due to the problems of mowing.

Fruit exhibited varying levels of damage, from no blemishing to severe surface russetting. It appears that the damage to nectarines by thrips is caused by feeding larvae rather than by oviposition activity or feeding by adult females (Pearsall, chapter 3). The relationship between adult and larval densities and subsequent fruit damage in each orchard is examined in a following paper (Pearsall, chapter 3). The minute scars that larvae cause on the tiny developing ovary grow into large areas of scarred and russeted tissue as the nectarines grow in size. Once the husk dries up, the larvae are protected from any spraying. Larvae do not appear to move about on trees but remain protected within the fruit husk throughout the course of their development until they are ready to fall to the ground to pupate.

It is difficult to make comparisons across orchards in terms of WFT densities or damage levels, as some orchards were organic whereas others received pesticide sprays. Pesticide sprays of Diazinon at pink or petal fall in 1993 did not appear to result in low levels of damage in those orchards in which they were carried out. Although application of the pesticide Thiodan during the pink or bloom stage did appear to result in a short term reduction in numbers of adults within buds in orchards A, I and J (pers. obs), the latter two orchards still received unacceptable levels of damage. This suggests that either the chemicals themselves or the timing of application may be ineffective.

In addition to pesticide use, there was variability among orchards in terms of their location within valleys. For 1993, orchards bordering patches of wild land (A, B, C and F) had higher densities of buds infested both by adult and larval western flower thrips, and higher levels of fruit scarring than orchards surrounded entirely by other blocks of trees (D, H). With the exception of orchard A, this pattern also was the case in 1994. Factors other than location, such as orchard exposure to wind flow which carries dispersing WFT, also may play a role. Orchards D and H were the least exposed orchards, both almost fully



surrounded by other orchards and thus highly protected from wind. Orchards A, C, I, J, and K are the most highly exposed with more than two sides open to wind, with orchards B, E, F, G and L open on more than one side to wind. Other sources of variability among orchards are the varieties of nectarine grown and the rate of development of the fruit buds. This latter factor appeared to vary due to microclimate effects, with similar varieties of nectarines exhibiting large differences in rate of development dependent upon the location of an orchard within the valley.

Although the period between buds coming out of dormancy and full bloom was longer in 1993 than 1994, the opposite situation was apparent for the period between the occurrence of larvae in petal fall bud to the emergence of the first generation adults which was shorter in 1993 than 1994. The bloom progression data for orchard E showed that the period between petal fall and husk-fall was very long in 1994, as temperatures fell at this time. Thus, although the period for egg-laying was likely longer in 1993, the period for larval feeding activity was longer in 1994. This extended period of larval residence within buds, together with generally higher adult and larval densities in 1994, may account for the increased damage seen in 1994 as compared with 1993 in those orchards not sprayed with Thiodan at pink (B, C, D, E). Orchards A, I and J were less severely damaged in 1994, probably because they received an application of Thiodan at the pink stage of nectarine development in 1994. In addition, bud development at petal fall was particularly rapid in orchard A in 1994, which may have reduced the larval hatch occurring after the husks had fallen from the trees. Steiner (1990) suggested that damage to cucumber fruit in greenhouses was related not only to density of WFT but also to the rate of growth of the fruit.

In conclusion, WFT was the most abundant and injurious species of thrips found in nectarine orchards in the Dry Central Interior, although densities were variable among orchards and the two years of study. However, orchards located in protected locations had consistently lower densities of WFT and subsequent damage than orchards located adjacent

to wild land, which appeared to be a huge source area for emerging WFT in the early spring.

## CHAPTER 3

### POPULATION DYNAMICS PART II

#### **Evaluation of sampling methodology for determining the phenology, relative density and dispersion of Western Flower thrips, *Frankliniella occidentalis* (Thysanoptera:Thripidae).**

**ABSTRACT:** Western flower thrips cause serious economic damage to nectarines in the Dry Central Interior, British Columbia, Canada. We studied the phenology of WFT damage with several sampling methodologies between 1993 and 1995 to determine the most susceptible period for damage by WFT to nectarine fruit, the life stage responsible for damage, and variation in susceptibility to damage of 11 different varieties. Beating, flicking and visual estimation methods are not appropriate for estimating numbers of thrips in nectarine buds. Sticky cards show general population trends but are less efficient than bud sampling. Sampling of WFT in the field underestimated the density of both adults and larvae, and for adults, underestimated the proportion of the pale morph of WFT. Female WFT appear to lay eggs in nectarine buds from dormant through bloom stages. Eggs are laid primarily in sepal tissues in the early buds and in filaments and petals as these become available throughout bud development. Damage to nectarines is caused almost entirely by larval feeding at petal fall. Varieties did not differ in terms of larval densities at petal fall or the subsequent damage to fruit .

**KEY WORDS:** Western flower thrips, *Frankliniella occidentalis*, damage, nectarines, sampling methodology, variety effects, stonefruit IPM

### **3.1 INTRODUCTION**

Western flower thrips cause sufficiently serious damage to nectarines in the Dry Central Interior, British Columbia, to make many growers consider replacing their blocks of nectarine trees with other fruit species that are less susceptible to thrips attack. The damage results in serious russetting of the fruit surface tissue, which may be very

pronounced on the mature fruit. Female WFT become active in orchards in this region in the early spring and can be found concentrated on the developing nectarine buds (Pearsall, chapter 2). Larvae hatch from the eggs at petal fall. It is commonly believed that russetting is caused by the feeding of the larvae at petal fall.

Very little information exists on sampling techniques for these insects in the field situation, or the densities of WFT that would constitute a serious attack, and indeed, even when the damage occurs. Sampling methods and protocols have been developed for thrips in roses, apples, cotton, soybean, and onion (Ota, 1968; Lewis, 1973; Henneberry *et al.*, 1974; Chander and Verma, 1978; Irwin and Yeargen, 1980; Edelson, 1985) but few are statistically based (Irwin *et al.*, 1979; Salifu and Hodgson, 1987; Shelton *et al.*, 1987; Terry and DeGrandi-Hoffman, 1988). Sampling is central to any monitoring program, and must be cost effective and feasible for growers or field scouts to perform. Monitoring strategies may be based on absolute or relative estimates. Techniques for estimating absolute density include emergence cages, quadrats, or counting thrips on whole plants, while sticky traps are commonly used to provide relative estimates. Errors in counting may bias results using absolute techniques and relative estimates may be biased if traps vary in the proportion of the population attracted to them, and the capture efficiency. Relative estimates are strongly affected by weather and behavioural states of individuals, for example, whether they are involved in reproduction or migration (Southwood, 1978). However, relative estimates are the preferred choice when it is critical to obtain early information about pest infestation when densities are low. The choice of trap, particularly its size, colour and placement may be critical to its success. Sample size and sampling pattern are also important considerations.

The most commonly employed methods of sampling for WFT are the use of water traps, sticky cards and destructive sampling of either whole plants or plant parts, such as fruits or blossoms (Terry and DeGrandi-Hoffman, 1988; Gillespie and Vernon, 1990; Yonce *et al.*, 1990a,b; Salguero Navas *et al.*, 1991a&b). We wished to examine the

relative efficiency of both invasive (destructive) and non-invasive sampling methods, namely, bud sampling, bud flicking, branch beating and the use of sticky cards, and to determine which method has the most potential as an early warning system for growers to determine if and when WFT are present within their crops.

Together with determination of the accuracy of various methods of sampling, is a need to examine the spatial pattern of a pest within a crop, such that appropriate sampling plans may be developed. Thus, we also examined the spatial characteristics of the populations of WFT both within and among orchards, and how dispersion characteristics of WFT varied with changes in density. Using aggregation indices calculated with Taylor's power law (Taylor, 1961) and Iwao's patchiness regression (Iwao, 1968), we determined the sample sizes required to satisfy various levels of precision and to determine whether current sampling methods would fall under these guidelines. In addition, knowledge of the dispersion pattern is useful for selecting appropriate transformations for stabilizing variance for statistical analyses of field data.

Damage by thrips to nectarines has been studied in California (LaRue *et al.*, 1972), France (Bournier, 1970; Grasselly *et al.*, 1993), Greece (Kourmadas *et al.*, 1982), Italy (Cravedi *et al.*, 1983; Cravedi and Molinari, 1984), Spain (Lacasa *et al.*, 1991), the southeastern United States (Yonce *et al.*, 1990a), Pennsylvania (Felland and Kleiner, 1992; Felland *et al.* 1993a,b, 1995) and New Zealand (Teulon, 1988; Teulon and Penman, 1987, 1991, 1996). Population densities and types of damage caused by WFT or the other species of thrips responsible for damage varied in these different locations. In France, Northern Spain, Italy, Greece, Pennsylvania and the southeastern US, most damage is apparent as a silvering of the fruit surface, caused by female WFT oviposition and feeding activity at the time of fruit swell. Felland *et al.* (1995) suggested that early-season infestations of WFT on nectarine do not occur in Pennsylvania due to late emergence from overwintering sites, a low overwintering survival, or both. In California, damage is caused both by larval feeding on the immature fruit at petal fall, which results in severe

russetting of the fruit surface, as well as the silvering injury. In New Zealand, both types of damage also appeared to occur. In the Dry Central Interior, growers report that russetting is the primary type of damage to fruit, and this appears to occur very early in the life of the fruit.

It is critical to determine the period of maximum susceptibility of the crop, for estimation of damage thresholds, and for successful pest management. Whether eggs are laid on developing nectarine buds, in one peak period or over a long period of time, and the bud stage at which egg-laying begins need to be known. We also wished to examine whether WFT females are highly discriminating in the locations chosen for oviposition, and whether the levels of fruit damage by thrips varied with the varieties of nectarines grown in this region.

The main objectives of this study were as follows:

- a) To identify appropriate and practical sampling techniques for WFT for the development of economic and damage thresholds;
- b) To examine the spatial dispersion of adult and larval WFT populations both among trees and among orchards;
- c) To determine the most susceptible period for fruit damage and to clarify whether most damage is due to oviposition activity in the flower buds or to feeding by larvae and adults;
- d) To determine whether differences exist among varieties of nectarines in the severity of damage caused by WFT;
- e) To examine the relationship between densities of thrips and scarring of fruit; and
- f) To quantify the extent of movement of WFT among flowers.

### 3.2 MATERIALS AND METHODS

#### Study Sites

Work was carried out in eleven different nectarine orchards (A-K) located in the Dry Central Interior, in the southern interior of British Columbia, Canada (Figure 3.1). Orchards A-H were located in the southern Dry Central Interior, near to Cawston, and orchards I and J were in a more northern part of the Dry Central Interior, near to Summerland.

#### Sampling methods

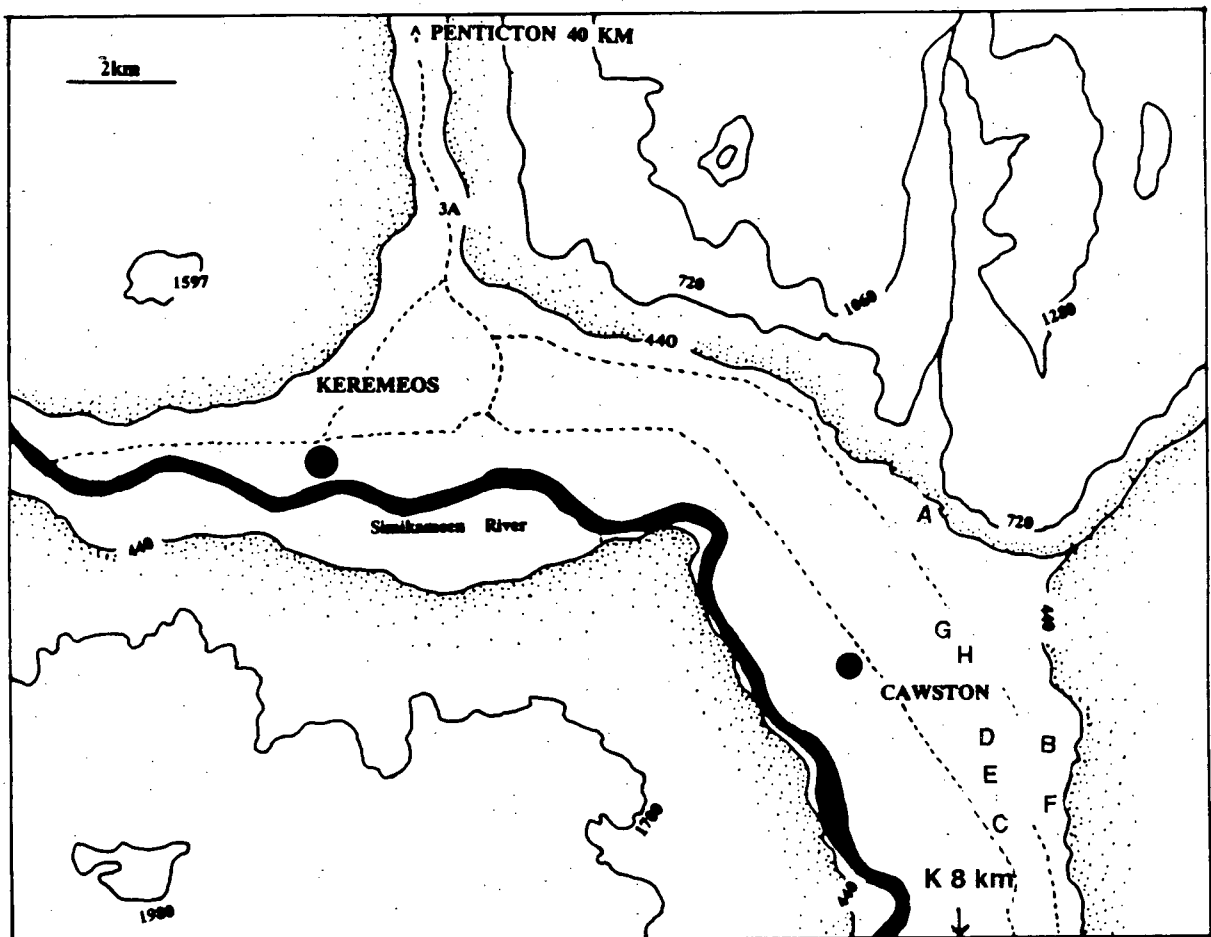
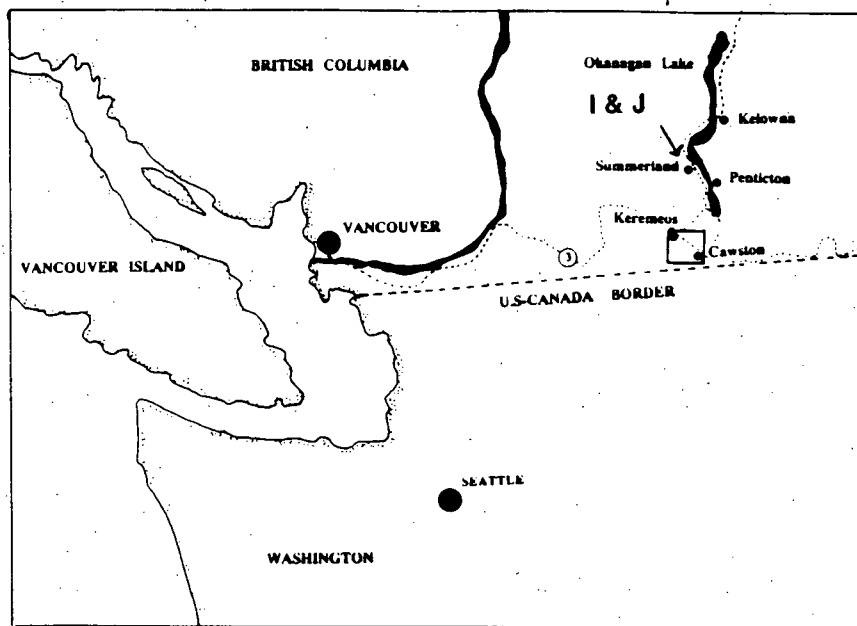
We compared both invasive and non-invasive sampling methods. The following sampling methods were performed and the densities of WFT compared:

##### *I Invasive procedures:*

1. 1993 & 1994: Direct counts of adult and larval thrips were made using a dissecting microscope in the laboratory. On each sampling occasion, 8-12 buds were collected from each of 6-15 sample trees per orchard, and placed into sealed Ziploc® bags.
2. 1993 & 1994: Between 50 and 100 buds or flowers were opened in the field to make rapid estimates of density of thrips per bud and the percentage of buds infested with either adult or larval thrips was determined.

##### *II Non-invasive procedures:*

1. 1993: Buds and leaves were "flicked" over bags or white cloths to collect the thrips for subsequent counts as outlined by Terry & DeGrandi-Hoffman, 1988. This method did not necessitate removal of the plant parts from the tree.
2. 1993: A branch of a tree was struck sharply three times over a beating board for rapid and non-invasive counts of WFT throughout the season.



**Figure 3.1** Location of orchards A-K in the Dry Central Interior, British Columbia, Canada.



3. 1993: Visual estimates of buds were made to determine whether we could make rapid counts of WFT per bud without removing the bud from the tree.
4. 1993: Sticky cards were hung within trees to trap flying WFT. Four sticky traps were hung in each of eight sample trees in orchards A, C and I. Each trap was constructed using a yellow sticky card which was attached to a length of wire by a large paper clip, and suspended from a tree branch in each quadrant of the tree.

In 1993 bud sampling and sticky card collection were carried out every few days from 5 April to 23 May. Flicking, beating and visual estimates were carried out when the trees were at the full pink and bloom stages. In 1994, field and laboratory counts of WFT in buds were carried out on several occasions between 28 March and 4 May. On-site counts of the numbers of adult and larval thrips per bud for both 1993 and 1994 were compared with results from buds collected and counted in the lab to determine the relative accuracy of field counts. Counts on the sticky cards from orchards A, C and I were compared with counts of thrips made from the buds or flowers and with subsequent larval densities and subsequent fruit damage per tree using linear regression.

Sampling precision for the bud sampling and sticky card methods was estimated in each orchard where applicable by calculating the relative variation (RV) for each sampling date, where  $RV = (SEM/Mean) \times 100$ . To compare differences in the relative variation between sampling methods, I calculated the mean RV values over the period of bud development for each method. Sampling efficiency also was calculated for each technique as the relative net precision (RNP) =  $100 / [(RV_m)(C_u)]$  where  $RV_m$  = the mean relative variation and  $C_u$  = the cost in minutes to count thrips abundance on an individual sample unit, or mean search time (Pedigo *et al.*, 1972; Karandinos, 1976; Zar, 1984; Hall *et al.*, 1991; Buntin, 1994). RV values are a simple estimate of the precision of a sampling technique: values of 25% or less may be acceptable for general estimates although some research purposes would require values of 10% or less (Southwood, 1978).

## **Determination of fruit damage**

With the aim of eventual development of economic and damage threshold levels for this insect in nectarine, we used linear regression to examine the relationship between density of adult thrips and damage, and the relationship between density of larval thrips and damage. Between eight and twelve buds were taken randomly from each of 6-15 trees per orchard on several occasions throughout nectarine bud development in both 1993 and 1994. Mean numbers of adults per tree collected prior to petal fall (total number of adult WFT divided by the total number of buds for all sampling occasions prior to petal fall) were regressed against mean damage levels per tree for orchards A to K for both 1993 and 1994. Both larval counts made in 1993 were regressed against damage per tree. Many collections of larvae were made in 1994, and so we simply regressed the overall mean density of larvae per tree against damage per tree. For both years, peak larval counts per tree also were regressed against damage. In addition, the number of adults collected from dormancy to bloom also were regressed against the number of larvae estimated per tree. We did not include adult counts for post-bloom stages since we assumed that egg-laying at bloom or earlier in bud development would result in larval hatch at petal fall. Finally, mean values of adult and larval estimates for each orchard were calculated and the same regressions were carried out among orchards using the mean number of adults, larvae and damage per orchard.

In both years fruit was rated for injury by thrips twice between petal fall and harvest. Injury on 15 to 25 fruit per sample tree was scored using a numerical scale from no damage at 1, slight scarring at 2, to severe deformation at 7. In 1993, damage assessments took place on 29 May and 26 June for the southern orchards, and on 28 June and 3 July for the northern orchards. In 1994, fruit damage was assessed on 18/19 May and 25 May (shortly after husk-drop) and again on 10/11 and 12 July (about 3/4 -sized fruit) for the southern and northern orchards, respectively. Final damage levels at harvest were estimated by the growers for some of the orchards. These three damage assessments

of fruit were carried out because fruit thinning by the growers and natural fruit drop resulted in selective removal of damaged fruit, thus damage levels at harvest were much lower than those as assessed shortly after husk fall.

### **Dispersion characteristics**

For both 1993 and 1994 adult and larval thrips were counted several times between dormancy and husk drop in 12 buds per tree for 8 - 15 trees in at least ten orchards giving a total of 121 nectarine trees in 1993 and 190 nectarine trees in 1994. Buds were chosen randomly from within a tree as a previous study indicated that both adult and larval WFT showed no position effects within a tree (Pearsall, chapter 2). These counts were used to estimate the parameters for two mean-variance models: Taylor's power law and Lloyd's (1967) mean crowding index,  $m^* = m + (s^2/m - 1)$ .

The coefficients  $a$  and  $b$  of the Taylor power law,  $s^2 = am^b$ , were estimated from the regression equation,  $\log(s^2) = \log(a) + (b) \log(m)$ , where  $a$  and  $b$  = the intercept and slope coefficients, respectively. The slope ( $b$ ) is a measure of aggregation, and the intercept ( $\log a$ ) is a scaling factor related to sample size. It is commonly accepted that a regression slope of 1.0 indicates random dispersion, a slope  $< 1.0$  a uniform dispersion, and aggregation when the slope is  $> 1.0$  (Taylor, 1961; Harcourt, 1965; Southwood, 1978).

Iwao's method (Iwao, 1968) is calculated by solving the equation  $m^* = \partial + \beta m$ , where  $\partial$ , (estimated by  $a$ ) = the intercept on the ordinate, and  $\beta$ , (estimated by  $b$ ) = the slope of the regression line when  $m^*$  is regressed on the mean ( $m$ ). Mean crowding ( $m^*$ ) was derived from Lloyd's Index of mean crowding formula (Lloyd, 1967), where  $m^* = m + (\phi^2/m - 1)$ , substituting the mean and variance for the count data. Here, the slope  $\beta$  is a density-contagiousness coefficient related to how an organism uses its habitat, where  $\beta > 1$  denotes a clumped distribution,  $\beta = 1$  a random (Poisson) distribution and  $\beta < 1$  is

undefined. The intercept  $\partial$  is a measure of crowding, with negative values suggesting a tendency for organisms to repel one another (Southwood, 1978).

The above parameters were determined for both years for each of the following bud developmental stages: petal show (for 1994 only), pink, bloom, late bloom and petal fall. Petal show is the bud developmental stage at which petal is first visible as the swelling bud begins to open up (Pearsall, chapter 2). T-tests were used to determine if the regression slopes and intercepts for the two years (1993 and 1994) differed significantly. We also examined dispersion characteristics using within-tree abundance data for larvae: in orchard C in 1994, 16 buds were taken from each of four within-tree strata from each of eight trees at the petal fall stage. Finally, these parameters were determined for each sampling occasion for the tree card data discussed above.

The regression parameters that gave the highest coefficient of determination ( $r^2$ ) were used to determine required sample sizes of trees at a fixed levels of precision of 0.25 using Cochran's (1977) equation,  $n = am^{b-2}/D^2$  (where  $n$  is required sample size,  $m$  is the mean value of thrips per tree,  $D$  is a fixed level of precision and  $a$  and  $b$  are taken from Taylor's power law). This level of precision was chosen based on Southwood's (1978) recommendation that such a level is adequate for pest management applications as it represents a reasonable balance between high precision and impractically high sample size.

### **Determination of when eggs are laid**

Two methods were used to determine when eggs were laid. In 1993 and 1994, we attempted to determine the optimal period for egg-laying by enclosing buds in mesh bags. In 1995, buds were removed from trees at various stages of development for staining and microscopic examination of eggs.

### *I Exclusion Experiments:*

1993: To determine the period of time during which adult thrips lay eggs in the developing buds, the following experiment was carried out in three of the orchards (C, G, & I) . On each of four sample trees in each orchard, 16 cages constructed out of fine mesh (Nytex screening, 2.9  $\mu$ m mesh, approximate cage dimensions: 5 cm by 10 cm) were placed over clusters of dormant buds in late March. This mesh size is too small to allow thrips entry into the bud. Four cages were removed from each of the trees at each stage of full pink (Treatment A), full bloom (Treatment B) and petal fall (Treatment C). The other four cages were placed around buds in the same way but were left open to act as control cages. The resulting fruit were removed from the tree at a size of 4 cm in length and the damage was assessed. This experiment allows determination of the period of time during which egg-laying by female thrips occurs, and the time period during which this results in the most serious damage.

1994: Cages were constructed from Nytex and duct tape (approximate dimensions: 15 cm by 30 cm) and on 1 March eighteen cages were placed on each of three trees in two orchards (E, I) and twelve cages on each of four smaller trees in a third orchard (B) while the trees were still in the late dormant stage. Cages were placed on sections of branches so that several buds were enclosed, although the numbers of buds enclosed were variable in each cage. Before caging, these sections were sprayed with dormant oil to prevent aphid hatch later in the spring and subsequent loss of buds within the cages. Cages were removed for five 'windows' of time and then replaced. These windows coincided with bud development. 1) The first 4-5 cages were removed as the buds began to swell, described as 'white swell' (Treatment B). At the same time 4-5 cages were placed over swollen buds which were not previously caged (Treatment A). 2) Once the B buds reached the stage "early petal show" when pink petal is faintly visible (a time when thrips are able to access the inside of the developing flower), they were again enclosed in cages, and 3) a further set of 4-5 cages were removed from early petal show buds (C). This continued for

two further windows: 4) removal at (D) full pink and 5) (E) bloom. Cages removed from bloom buds were not replaced. Once larval hatch had occurred, all the buds from each cage were put separately into vials of ethanol and the larvae counted.

## II Egg Examination

Eggs were stained using a method adapted by Teulon *et al.* (1993) from Backus *et al.* (1988). Egg counts were compared among buds of the following stages: white swell/pink colour (ws/pc), early petal show/petal show (eps/ps), pink and full bloom in orchards B and J (Figure 3.2). White swell/pink colour is the stage at which the dormant buds have swollen and the outer sepals have just taken on a dark pink colour. Early petal show/petal show occurs when a small amount of pink petal has just emerged from between the sepals, and is the stage at which we believed thrips would first be able to access the interior of the buds. Results from sampling buds in 1993-1995 showed that this was indeed the first stage during which we found thrips within blossoms (Pearsall, chapter 2). Full pink, also known as the 'popcorn' stage, is the stage when all the petals are visible and is the stage prior to full bloom.

Twenty-four buds were collected at each of the stages of development described above from each of two orchards (B and J). The buds were first placed for 48 hours in McBride's (1936) stain, which consisted of 0.2% acid fuchsin in 95% ethanol and glacial acetic acid (1:1 vol./vol.). Buds were then cleared for 48 hours in a clearing agent, which consisted of one part of each of the following: distilled water, 99% glycerine and 85% lactic acid (1:1:1 vol./vol./vol.), and bud tissues were examined under 250 power using a compound microscope. Position and number of eggs were compared among buds of each stage to assess when and where eggs are laid.

**Dormant Bud**



**White Swell (WS)**



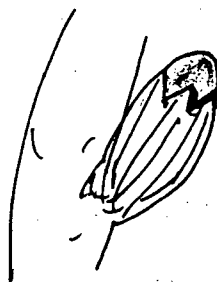
**Pink Colour (PC)**



**Petal Show (PS)**



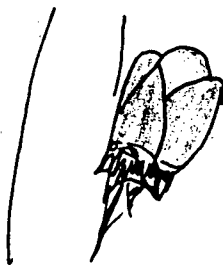
**Early Pink**



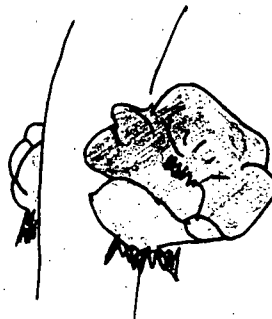
**Full Pink**



**Early Bloom**



**Full Bloom**



**Figure 3.2** Diagram of the various stages of development of nectarine buds from the time that buds come out of dormancy (white swell (ws)), through the stages of pink colour (pc), petal show (ps), pink and full bloom.

### **Determination of relative damage caused by adults vs. larvae**

This study aimed to determine the relative effects of oviposition by adult females and feeding damage by larvae on nectarine damage by carrying out microscopic examination of the ovary within the nectarine flower from the early pink stage (when adult females are first found within flowers) until husk drop (once all the larvae have dropped from the tree). Damage was rated from 1 to 5 where 1 denoted no damage; 2, 0-25% of ovary marked; 3, 25-50% of ovary marked; 4, 50-75% of ovary marked; and 5, 75-100% of ovary marked. A sample of 25 fruitlets (ovaries) were examined from orchard C on each successive bud development stage from petal show to bloom for 1994 only. A total of 50 buds were examined three times during the stage of petal fall. We also wished to examine the percentage of buds that appear to be affected by thrips at husk fall and compare this with successive damage assessments made over the summer during which damaged fruit is both preferentially thinned and fruit drop results in loss of some fruit due to its failure to 'set' on the tree.

### **Variety comparisons**

Comparisons across varieties could only be made within orchards rather than among orchards because of the variability among orchards in thrips attack. In general, the densities of thrips entering different orchards varied significantly dependent upon their location (Pearsall, chapter 4). Different varieties within an orchard were generally segregated on different rows. Because we did not identify any differences in thrips density with location of trees within orchards (Pearsall, chapter 2), it was assumed that we could make comparisons across varieties within orchards, even though the varieties were not mixed randomly within the orchards.

Thus, in 1993 and 1994, densities of adult and larval thrips and resulting damage were compared for varieties Independence and Flavourtop in orchard H, Redgold and Fantasia in orchard I and Harblaze, HW106, Early Sungrand and Earlisscarlet in orchard J.



In 1994 only the densities of adult and larval thrips and resulting fruit damage were compared among trees of variety Early Sungrand, Crimsongold, Rubygold and Redgold in orchard G.

### **Female dispersal**

Forty females coated with a bright pink fluorescent marker dye (Day-Glo® Daylight Fluorescent Pigment, Switzer Brothers Inc., Cleveland, Ohio) were placed separately on apple blooms such that each female was placed on a separate tree. Females were placed in open "king" blooms which were first shaken and checked to determine that no other thrips were already present inside. After two days the same buds were removed from the trees, placed into separate plastic bags and taken back to the laboratory where they were checked under a UV lamp, and the number of females remaining in the blooms counted.

### **Data Analysis**

A level of  $P < 0.05$  was taken to be significant for all statistical comparisons. Data were analysed using parametric ANOVA and t-test (independent and paired) from SYSTAT (Wilkinson, 1990). Where heteroscedasticity precluded the use of ANOVA, and where numbers could not be adequately transformed, the non-parametric Kruskal-Wallis test was used. Tukey's HSD test was used for all post-hoc comparisons of ANOVA results. A Mann-Whitney U test was used for post-hoc comparisons of all Kruskal-Wallis results with a Bonferroni adjustment to control the experiment wise probability of a type I error to 5%.

### 3.3 RESULTS

#### Sampling

Beating and flicking were carried out on each of eight trees in four orchards (B, E, F, K) in 1994. The numbers of WFT caught on the beating trays were almost zero in most cases: this was also true for the flicking technique (Table 3.1). It was also virtually impossible to detect adults by visual inspection of buds at any stage of bud development (Table 3.1). Thus, it is necessary to use either sticky cards or invasive sampling to determine densities. In the case of invasive sampling, the more rapid and less laborious method of estimation is sampling directly on site rather than carrying buds back to the lab for microscopic examination, thus we wished to compare the two methods thoroughly. Sampling on site also has the advantage of providing information on the density of larval or adult thrips within each bud or bloom and the percentage of buds infested, whereas eight or 12 buds were pooled into a bag for laboratory samples, and thus it was not possible to get such information. On-site counts of larvae were performed in orchards A, B, C, E, F, I and J in 1993 and in orchards A, B, C, D, F, J and K in 1994. On-site counts of adults were performed in 1994 only in orchards A, B, C, F, J and K. Only those field counts that were performed on the same time and day as the laboratory collections were compared. These comparisons were carried out more than once in some orchards. The on-site counting method consistently underestimated the density of thrips in all orchards tested, with the slopes of the regressions significantly less than 1 in each case (lab versus field larvae 1993:  $F=13.83$ ,  $df=1,6$ ,  $P=0.01$ ; lab versus field adults 1994:  $F=124.7$ ,  $df=1,7$ ,  $P=0.000$ ; lab versus field larvae 1994:  $F=15.15$ ,  $df=1,5$ ,  $P=0.011$ ) (Figures 3.3a,b,c). This was the case for both larval and adult counts. In the case of the on-site versus laboratory comparisons of adult densities in 1994, although the relationship between on-site and laboratory estimations was weak, there was a general tendency for the field

Figure 3.3a 1993

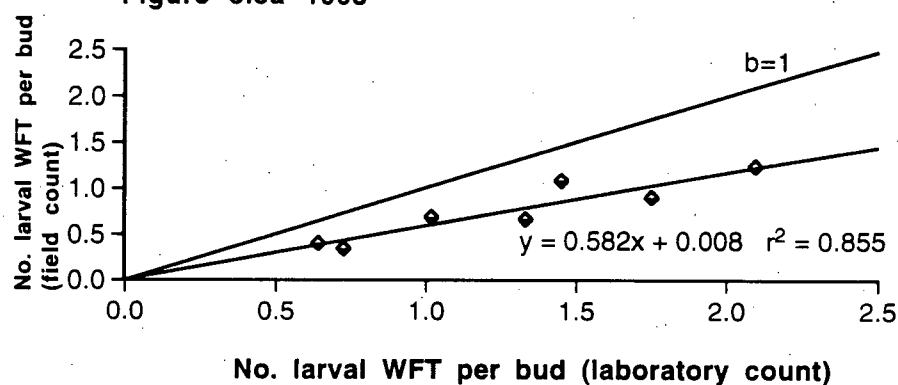


Figure 3.3b 1994

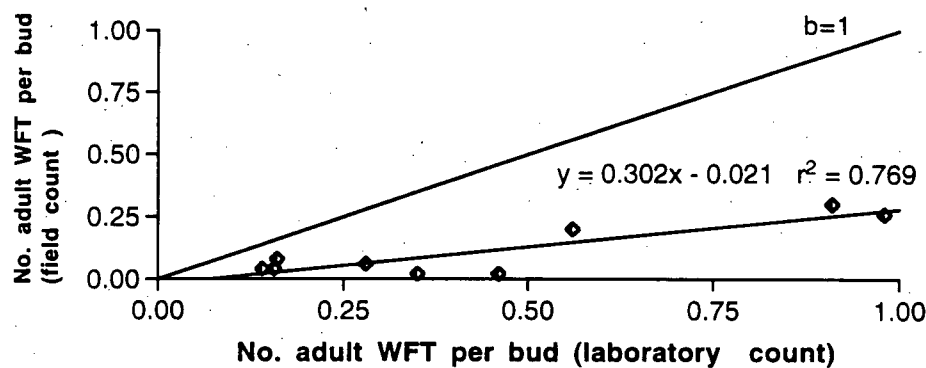
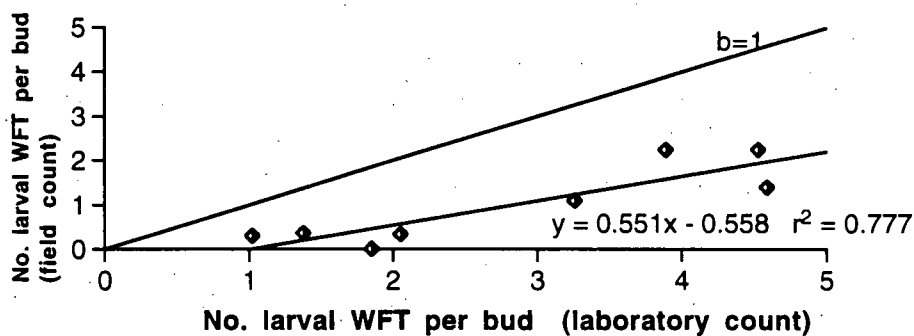
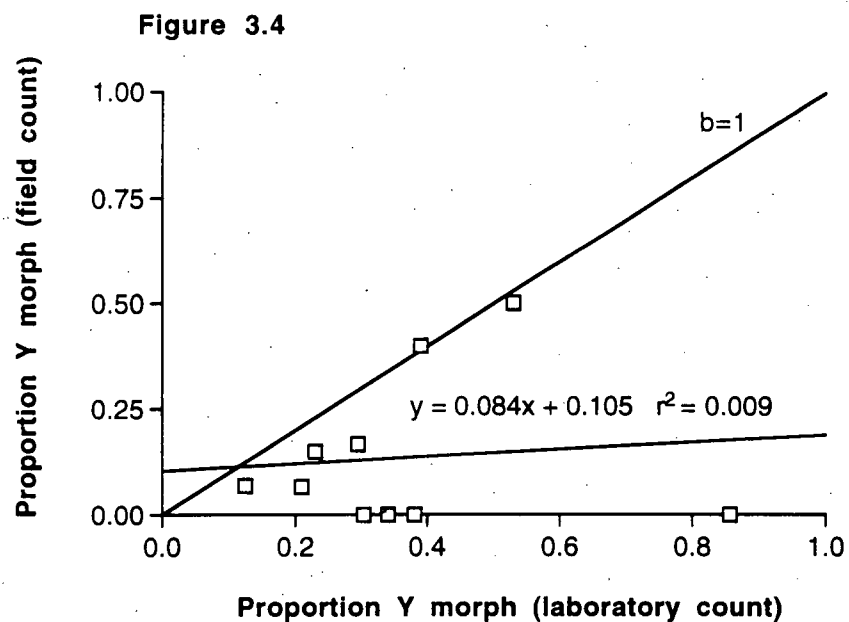


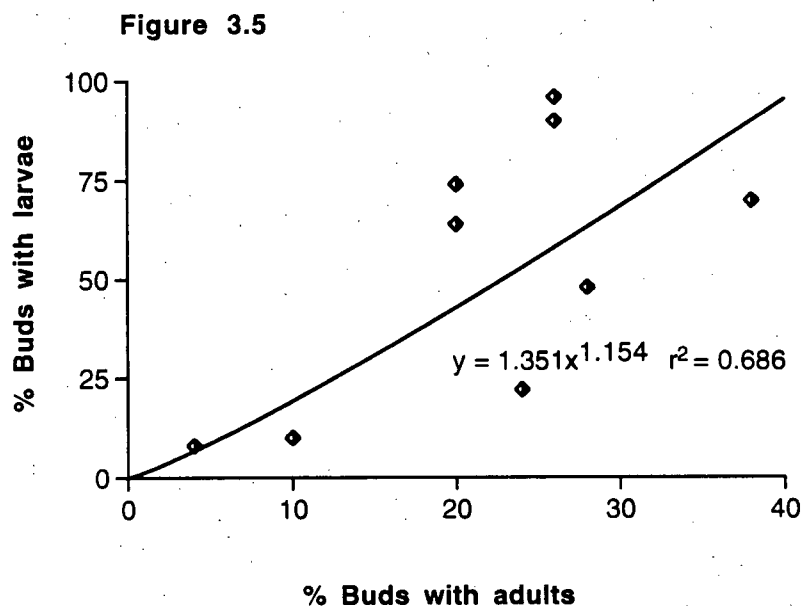
Figure 3.3c 1994



**Figure 3.3a-c** Relationship between a) laboratory counts of larval WFT versus on-site estimations of larval densities per bud as carried out in 1993 ( $F=29.43$ ,  $df=1,5$ ,  $P=0.003$ ); b) laboratory counts of adult WFT versus on-site estimations of adult densities per bud as carried out in 1994 ( $F=23.34$ ,  $df=1,7$ ,  $P=0.002$ ); and c) laboratory counts of larval WFT versus on-site estimations of larval densities per bud as carried out in 1994 ( $F=13.83$ ,  $df=1,6$ ,  $P=0.004$ ). The line with slope  $b=1$  is given so the extent of underestimation can be visualised.



**Figure 3.4** Relationship between laboratory estimation versus on-site estimations of the proportion of the pale morph WFT as carried out in 1994 ( $F=0.08$ ,  $df=1,8$ ,  $P=0.79$ ). The line with slope  $b=1$  is given so the extent of underestimation can be visualised.



**Figure 3.5** Relationship between the proportion of buds infested with adult WFT at pink versus the proportion infested with larvae at petal fall as assessed by on-site examinations of buds in 1994.

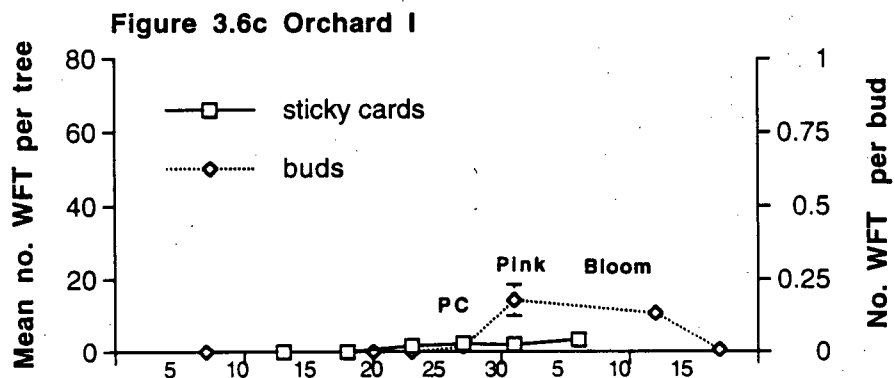
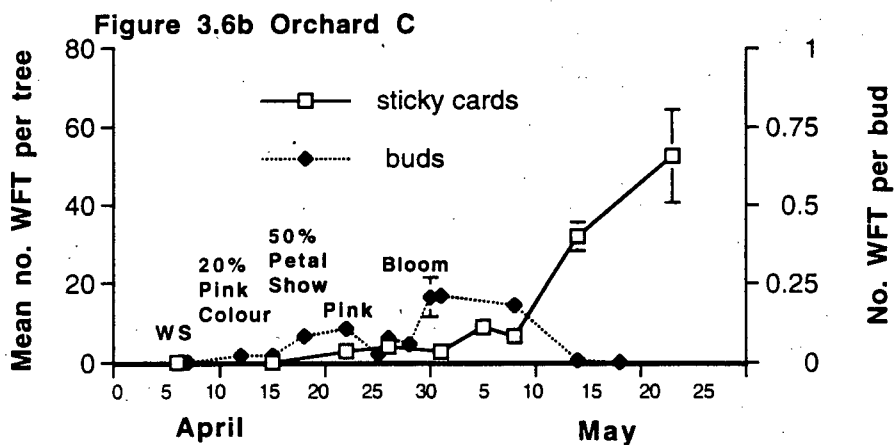
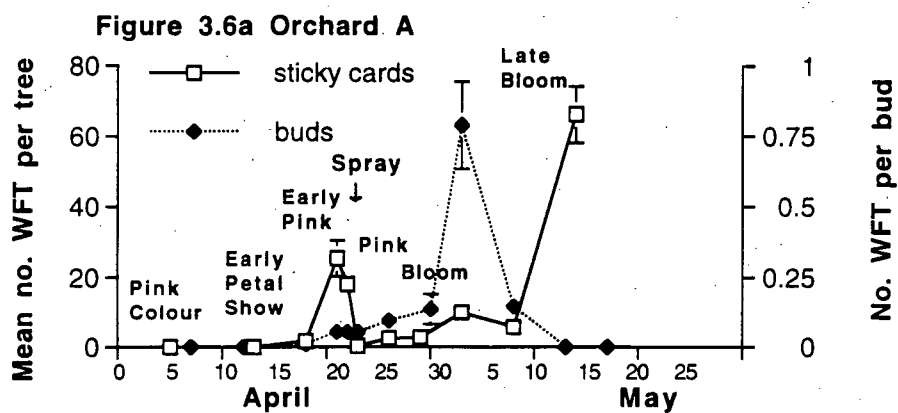
estimation to overestimate the density of the dark morph of WFT and underestimate the density of the pale or yellow morph (Figure 3.4).

**Table 3.1** Mean WFT per tree (for a total of 12 buds per tree and eight trees per orchard for each of the visual estimates, flicking and bud counts except for orchard F, where numbers of WFT are from eight buds from each of six trees). Beating was carried out for one branch per tree. The same trees were used for each sampling strategy. Associated standard errors are given in parentheses.

| <b>Orchard</b>    | <b>B</b>       |                | <b>F</b>       |                 | <b>E</b>       |                | <b>K</b>       |                |
|-------------------|----------------|----------------|----------------|-----------------|----------------|----------------|----------------|----------------|
| <b>Bud stage</b>  | Pink           | Bloom          | Pink           | Bloom           | Pink           | Bloom          | Pink           | Bloom          |
| <b>Beating</b>    | 0.00<br>(0.00) | 0.13<br>(0.13) | 0.25<br>(0.64) | 0.00<br>(0.00)  | 0.00<br>(0.00) | 0.88<br>(0.40) | 0.38<br>(0.18) | 0.50<br>(0.27) |
| <b>Flicking</b>   | 0.00<br>(0.00) | 0.13<br>(0.13) | 0.25<br>(0.16) | 0.38<br>(0.18)  | 0.00<br>(0.00) | 0.75<br>(0.16) | 0.10<br>(0.13) | 0.50<br>(0.19) |
| <b>Visual</b>     | 0.00<br>(0.00) | 0.25<br>(0.16) | 0.13<br>(0.13) | 0.13<br>(0.13)  | 0.00<br>(0.00) | 0.38<br>(0.18) | 0.50<br>(0.27) | 0.00<br>(0.00) |
| <b>Bud counts</b> | 3.75<br>(0.73) | 4.50<br>(1.17) | 2.88<br>(0.69) | 12.57<br>(2.40) | 2.57<br>(0.67) | 3.67<br>(0.56) | 3.00<br>(0.58) | 4.14<br>(1.10) |

The relationship between the percentage of buds infested with adults and the percentage of buds infested with larvae in 1994 as determined by on-site counts was better described by the power function  $y=1.35x^{1.15}$  ( $r^2 = 0.69$ ) than by simple linear regression ( $y=2.19x + 5.77$ ,  $r^2 = 0.43$ ), suggesting that larval infestation does not increase in a simple linear fashion as a result of increasing adult infestation (Figure 3.5).

We compared the numbers of WFT on sticky cards with numbers from bud counts carried out in the laboratory since both these methods were performed every few days throughout the nectarine bud development period. WFT appeared in bud samples before they were found in tree cards in orchard C, but were found on sticky cards before bud samples in orchard I, which contained the lowest density of WFT. In orchard A, WFT were present in buds and sticky cards at about the same time (Figures 3.6a,b,c). WFT adults were first found in bud samples on 18, 11 and 27 April, in orchards A, C and I, respectively. During this period of early spring in April, WFT were found in high numbers



**Figure 3.6a-c** Estimates of the numbers of WFT per bud (from sampling 12 buds from each of eight sample trees) and the numbers of WFT per tree (from counts of WFT on four sticky cards (\* two sides) hung within each of the eight sample trees) from a) orchard A, b) Orchard C and c) Orchard I between 5 April and 25 May 1993. Counts for sticky cards are expressed per tree (four sticky cards pooled).

in both dandelions (*Taraxacum officinale* Weber) and apricots (*Prunus armeniaca* Lam.), which were both in bloom prior to nectarine bloom (pers. obs.).

Patterns of WFT abundance on sticky cards and from bud samples also varied. In all three orchards, numbers of WFT on sticky cards increased gradually over bud development, with very high numbers recorded in mid to late May, no doubt as the first generation began to emerge. Bud counts showed various peaks between the time that buds began to swell and husk drop. At husk drop, bud counts dropped to zero as no WFT remained on the tiny developing fruitlet once the protective husk had fallen from the bud. In orchard A, WFT densities on sticky cards peaked at pink and were then found at very low numbers for a matter of days, no doubt the effect of the spray of the pesticide Diazinon which was carried out on 21 April. Peaks of adult numbers in both buds and sticky cards occurred at late bloom in this orchard. In orchard C, numbers of WFT in buds peaked at both pink and bloom/late bloom stages of development, whereas the numbers caught in the sticky cards showed only a small peak at late bloom. In orchard I, no clear peak of WFT was apparent from the sticky card catches until the increase seen as the first generation began to emerge, but there was an obvious peak in numbers of WFT from bud counts at the pink/bloom stage on trees.

*Regressions of adult WFT from sticky card catches against larval densities and damage. 1993:* We looked at the relationship of the catches on the sticky cards and larval densities at petal fall in each of the three orchards, A, C and I. Larvae were counted from both orchards A and C on 8 and 13 May, and from orchard I on 12 and 17 May. We regressed catches from sticky cards which were collected while trees in the orchards were at the early petal show, pink and bloom stages of development (Table 3.2) against densities of larvae from each of the two counts and against the peak count of larvae per tree for each orchard. In addition, we examined the relationship between these same counts of WFT from the sticky cards and the resultant damage per tree for each orchard.

**Table 3.2** Sticky card collections that correspond to the three different stages of bud development in orchards A, C and I.

| Orchard | Early petal show | Pink     | Bloom    |
|---------|------------------|----------|----------|
| A       | 18 April         | 22 April | 26 April |
| C       | 22 April         | 26 April | 1 May    |
| I       | 23 April         | 27 April | 1 May    |

Although fruit damage was assessed on several dates during both years, we decided to use the first damage assessment only (3 June for all orchards except G and J, June 28 for J, and 1 July for G in 1993, and in 1994, 18/19 May and 10 June, for the southern and northern orchards, respectively) to examine the relationships between adult and larval densities of WFT and subsequent damage. This was based on the fact that fruit thinning, which was carried out in the orchards after these dates, removed any conspicuously damaged fruit; thus the damage assessments made post thinning did not give a true estimate of the damage attributable to thrips.

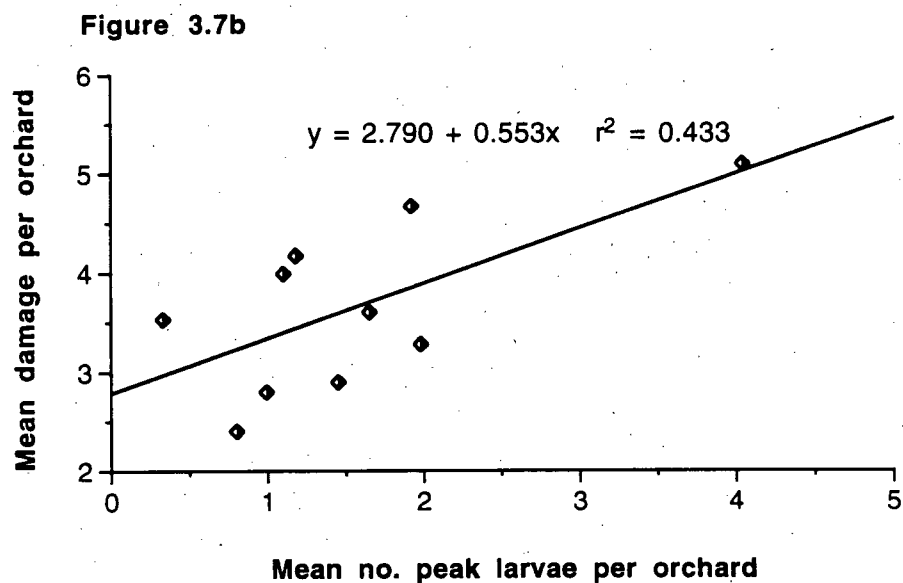
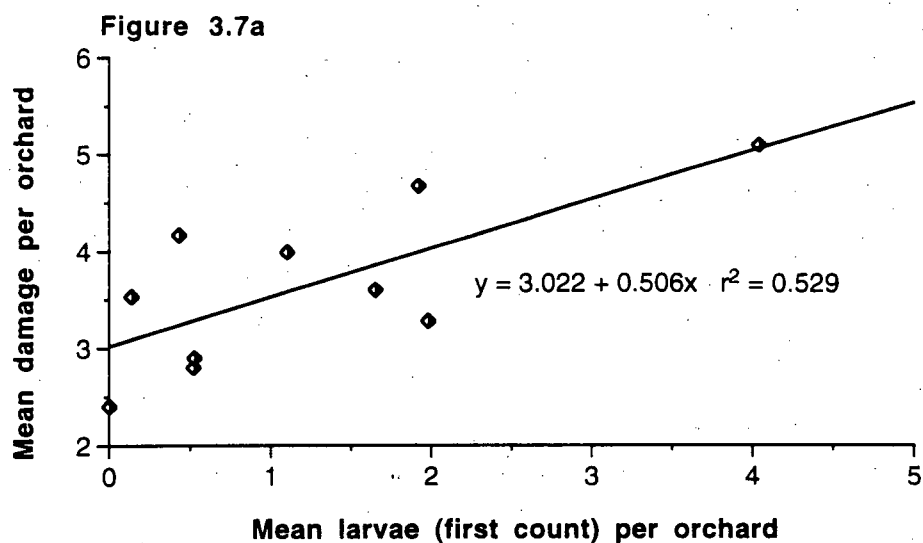
In general,  $r^2$  values were very low in orchard I and none of the regressions were statistically significant (Appendix 3.1). The catches of WFT on sticky cards collected on 26 April (buds at pink) and 1 May (buds at bloom) in orchard C showed a significant linear relationship with fruit damage per tree ( $F=16.37$ ,  $df=1,6$ ,  $P=0.007$  for 26 April and  $F=15.8$ ,  $df=1,6$ ,  $P=0.007$  for 1 May) but all the regressions against larval density were all non-significant (Appendix 3.1). In orchard A, there was a significant relationship between sticky card counts on 18 April (buds at early petal show) and both the first larval count ( $F=99.64$ ,  $df=1,6$ ,  $P=0.000$ ) and peak larval densities ( $F=78.80$ ,  $df=1,6$ ,  $P=0.000$ ). Regressions of densities of WFT on tree cards at pink (23 April) and bloom (26 April) in this orchard against larval densities and damage were all non-significant, as were the regressions of WFT on tree cards against damage for 18 April (Appendix 3.1).



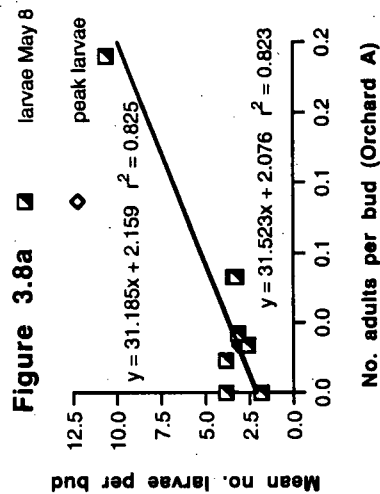
*Regressions of adult WFT, larval WFT from bud counts and damage 1993:* On an orchard scale, there was a significant linear relationship between the mean density of larvae (first count) per orchard and the mean fruit damage per orchard ( $F= 8.97$ ,  $df=1,8$ ,  $P=0.02$ ; Figure 3.7a) and the peak count of larvae per orchard versus damage ( $F= 6.11$ ,  $df= 1,8$ ,  $P=0.039$ ; Figure 3.7b) whereas there was no relationship between either the mean density of adult thrips per orchard and the first, second or peak counts of larval densities ( $F=0.86$ ,  $df=1,8$ ,  $P=0.38$  for the first larval count;  $F=0.42$ ,  $df=1,8$ ,  $P=0.54$  for the second larval count;  $F=0.60$ ,  $df=1,8$ ,  $P=0.46$  for the peak larval count) or subsequent damage ( $F=1.81$ ,  $df=1,8$ ,  $P=0.216$ ) and also no relationship between the second larval count and mean damage ( $F=0.695$ ,  $df=1,8$ ,  $P=0.429$ ).

Among trees within orchards, there was no consistent relationship between the total numbers of adult or larval WFT collected per flower bud between silver tip and petal fall per orchard and the subsequent mean fruit damage per orchard (Appendix 3.2). Only in two orchards were there any significant regressions: in orchard A, there was a significant relationship between the number of pre-petal fall adults and both the first larval count and the peak number of larvae recorded per tree ( $F= 27.904$ ,  $df= 1,6$ ,  $P=0.002$  for the first larval count;  $F=28.37$ ,  $df=1,6$ ,  $P=0.002$  for peak larvae; Figure 3.8a). In orchard C there was a significant regression of the density of adults caught pre-petal fall and the damage per tree ( $F= 8.353$ ,  $df= 1,6$ ,  $P=0.028$ ; Figure 3.8b). In addition, there was a significant linear relationship between the second count of larvae per tree and damage per tree in orchard A ( $F=12.43$ ,  $df=1,6$ ,  $P=0.012$ ; Figure 3.8c).

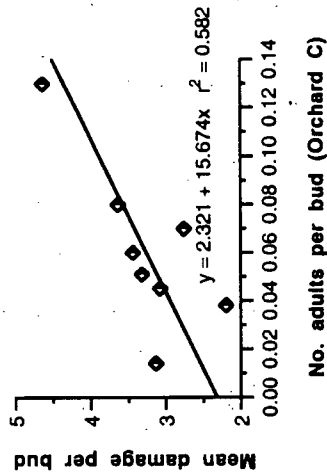
*1994:* There was a clear relationship between both the mean and peak densities of larval WFT per orchard and the mean damage per tree when expressed on a per orchard basis ( $F= 16.724$ ,  $df= 1,9$ ,  $P=0.003$  for mean densities,  $F= 13.143$ ,  $df= 1,9$ ,  $P=0.006$  for peak densities) (Figures 3.9 a,b). As for 1993, there was again no relationship between either the mean density of adult thrips per orchard and larval densities or subsequent damage ( $F= 1.975$ ,  $df= 1,7$ ,  $P= 0.203$  for larvae,  $F= 1.303$ ,  $df= 1,7$ ,  $P=0.291$  for



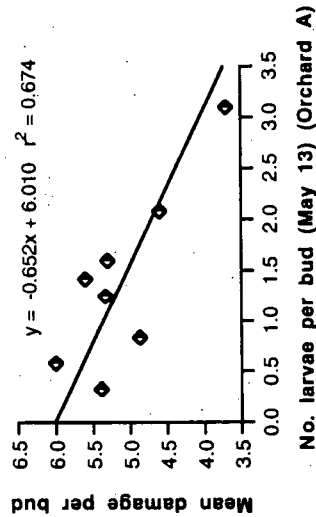
**Figure 3.7a,b** Relationship between a) the mean density of larval WFT (first count) per orchard and mean fruit damage per orchard in 1993; and b) the peak density of larval WFT per orchard and mean fruit damage per orchard in 1993, as examined using linear regression.



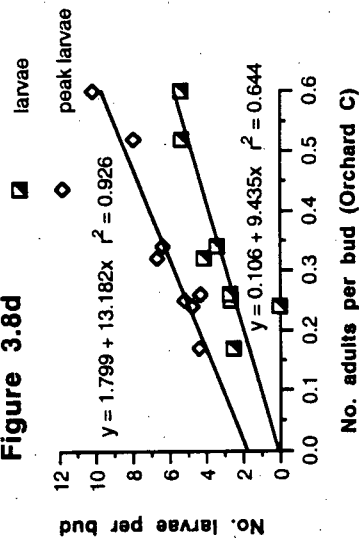
**Figure 3.8b**



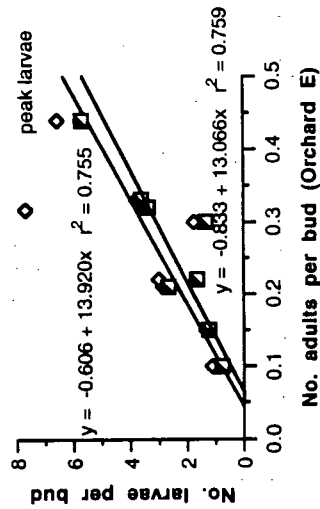
**Figure 3.8c**



**Figure 3.8d**



**Figure 3.8e**



**Figure 3.8a-e** Relationship between a) the mean density of adult WFT pre-petal fall per tree and both the number of larval WFT (first count) and the peak number of larvae per tree in orchard A in 1993; b) the mean density of adult WFT pre-petal fall per tree and the mean damage per tree in orchard C in 1993; c) the mean number of larvae per tree (second count) and the mean damage per tree in orchard A in 1993; d) the mean density of adult WFT pre-petal fall per tree and the subsequent densities of larval WFT per tree in orchard C in 1994; and e) the mean density of adult WFT pre-petal fall per tree and the subsequent densities of larval WFT per tree in orchard E in 1994, as examined using linear regression.

Figure 3.9a

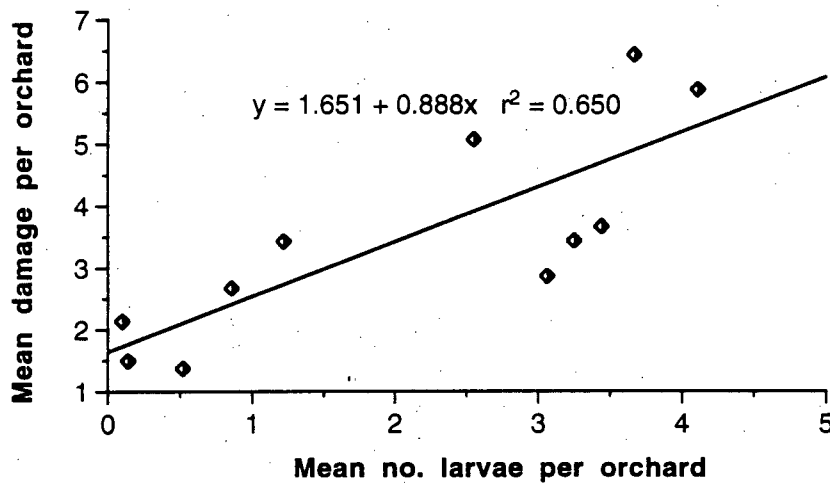


Figure 3.9b

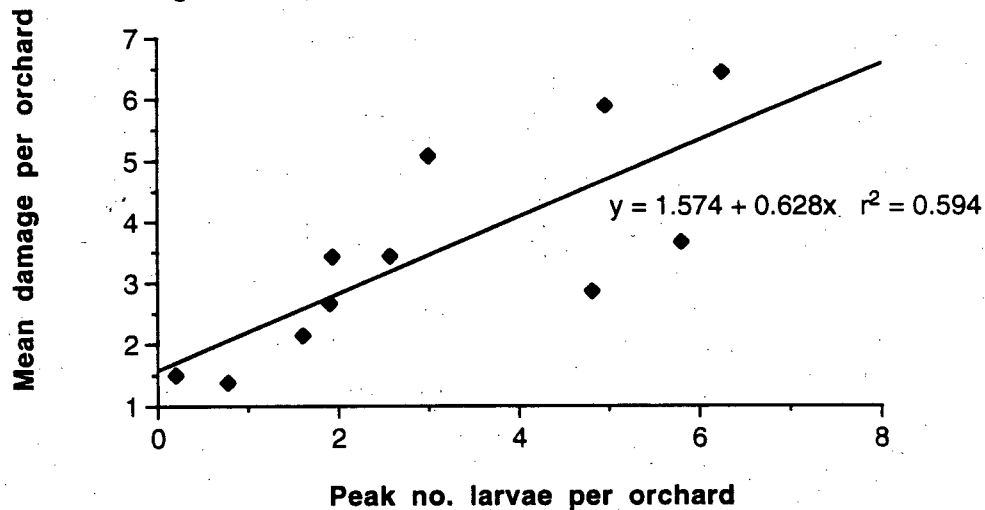


Figure 3.9a,b Relationship between a) the mean density of larval WFT per orchard and mean fruit damage per orchard in 1994; and b) the peak density of larval WFT per orchard and mean fruit damage per orchard in 1994, as examined using linear regression.

damage). Within orchards, there were again no consistent relationships between the density of WFT larvae or adults per bud and the subsequent fruit damage on a per tree basis within any orchard (Appendix 3.2). The only exceptions were the regressions of pre-petal fall adults from orchard C and E and subsequent densities of larvae (Orchard C:  $F=10.851$ ,  $df=1,6$ ,  $P=0.017$  for mean densities of larvae and  $F=74.792$ ,  $df=1,6$ ,  $P=0.000$  for peak densities of larvae; Orchard E:  $F=18.936$ ,  $df=1,6$ , for mean densities and  $F=18.523$ ,  $df=1,6$ , for peak densities,  $P=0.005$  for both) (Figures 3.8d,e).

In general, therefore, neither the density of adult or larval thrips collected from blossoms prior to petal fall gave a simple indication of future possible damage on a per tree basis.

Relative net precision and relative variation values were computed for the laboratory bud counts and the sticky card catches for each date that sampling was carried out with both methods (Table 3.3)

**Table 3.3** Sampling efficiency calculated as the relative net precision for both bud and sticky card counts in Orchard A, Orchard C and Orchard I. Relative variation (RV) is calculated as  $RV=(SEM/mean)*100$ . Sampling efficiency was expressed as the relative net precision (RNP) where  $RNP=100/[(RV_m) * C_u]$ , where  $RV_m$  = the mean relative variation and  $C_u$  = the cost in minutes to count thrips abundance on an individual sample unit, or mean search time.

*a) Orchard A*

| Date | Bud Counts |        |      |              | Sticky cards |       |      |              |
|------|------------|--------|------|--------------|--------------|-------|------|--------------|
|      | Mean       | RV     | Cu   | RNP          | Mean         | RV    | Cu   | RNP          |
| 18/4 | 0.13       | 100.00 | 0.04 | <b>12.50</b> | 1.65         | 19.82 | 0.25 | <b>33.64</b> |
| 21/4 | 0.63       | 51.84  | 0.05 | <b>38.58</b> | 25.44        | 20.01 | 0.35 | <b>14.27</b> |
| 22/4 | 0.63       | 51.84  | 0.06 | <b>32.15</b> | 18.03        | 12.62 | 0.20 | <b>39.62</b> |
| 23/4 | 0.63       | 67.20  | 0.06 | <b>24.80</b> | 0.25         | 65.60 | 0.10 | <b>15.24</b> |
| 26/4 | 0.75       | 48.80  | 0.08 | <b>25.62</b> | 2.38         | 40.93 | 0.15 | <b>16.29</b> |
| 30/4 | 1.63       | 40.19  | 0.10 | <b>24.88</b> | 2.67         | 41.94 | 0.20 | <b>11.92</b> |
| 3/5  | 6.25       | 19.54  | 0.13 | <b>39.37</b> | 9.88         | 11.71 | 0.30 | <b>28.47</b> |
| 8/5  | 2.38       | 13.64  | 0.11 | <b>66.65</b> | 5.68         | 13.76 | 0.30 | <b>24.22</b> |
| 14/5 | N/A        | N/A    | N/A  | <b>N/A</b>   | 66.3         | 12.04 | 1.00 | <b>8.31</b>  |

*b) Orchard C*

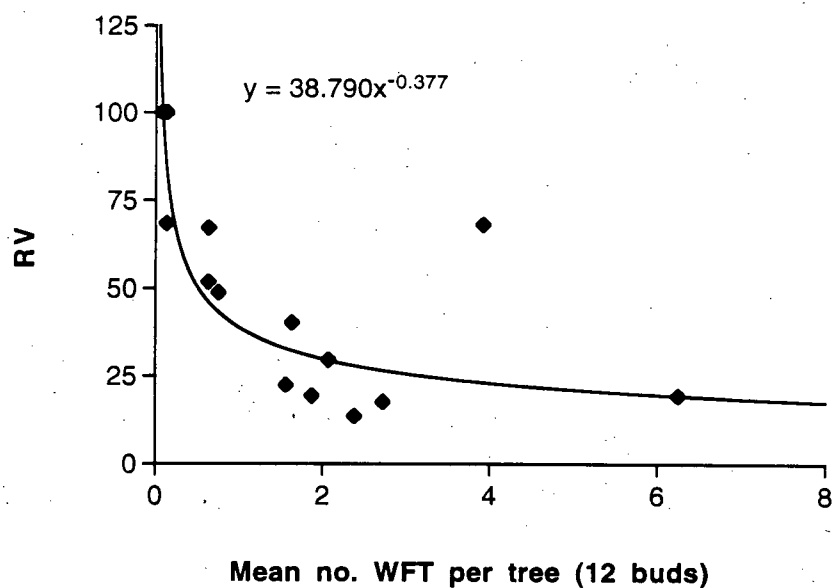
| Date        | Bud counts |       |      |              | Sticky cards |       |      |              |
|-------------|------------|-------|------|--------------|--------------|-------|------|--------------|
|             | Mean       | RV    | Cu   | RNP          | Mean         | RV    | Cu   | RNP          |
| <b>22/4</b> | 1.56       | 22.46 | 0.05 | <b>89.05</b> | 2.52         | 21.8  | 0.20 | <b>22.94</b> |
| <b>26/4</b> | 3.92       | 68.29 | 0.06 | <b>29.29</b> | 3.96         | 22.35 | 0.20 | <b>22.37</b> |
| <b>31/4</b> | 2.72       | 17.69 | 0.10 | <b>94.22</b> | 2.63         | 29.32 | 0.20 | <b>17.05</b> |
| <b>8/5</b>  | 1.87       | 19.44 | 0.08 | <b>51.44</b> | 6.54         | 23.99 | 0.23 | <b>18.12</b> |
| <b>14/5</b> | 0.07       | 100   | 0.02 | <b>50</b>    | 32           | 11.54 | 0.35 | <b>24.76</b> |

*c) Orchard I*

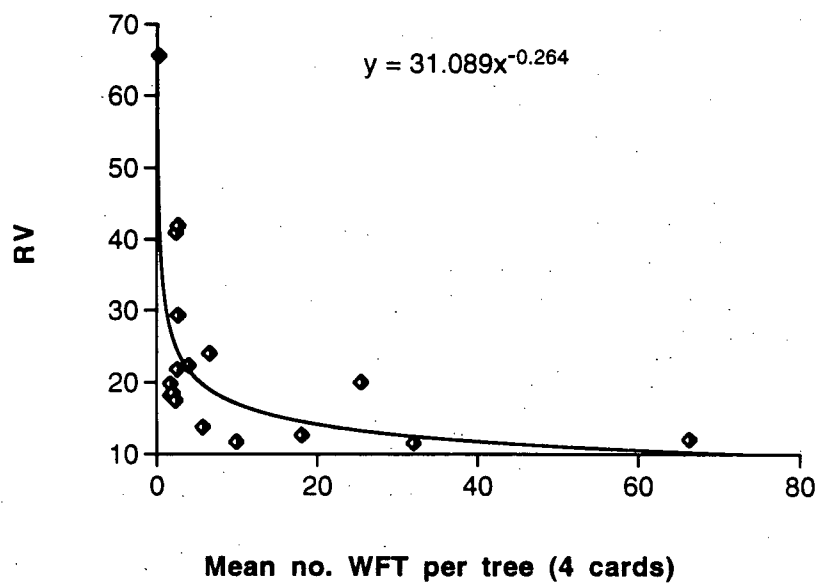
| Date        | Bud counts |       |      |              | Sticky cards |       |      |              |
|-------------|------------|-------|------|--------------|--------------|-------|------|--------------|
|             | Mean       | RV    | Cu   | RNP          | Mean         | RV    | Cu   | RNP          |
| <b>23/4</b> | 0.00       | N/A   | 0.02 | <b>N/A</b>   | 1.65         | 18.12 | 0.10 | <b>55.19</b> |
| <b>27/4</b> | 0.13       | 68.42 | 0.03 | <b>48.72</b> | 2.31         | 17.42 | 0.20 | <b>28.70</b> |
| <b>31/4</b> | 2.07       | 29.66 | 0.05 | <b>67.43</b> | 1.97         | 18.49 | 0.17 | <b>31.81</b> |

In general, relative variation values were lower for sticky cards than bud counts, indicating that there was greater sampling precision with sticky cards. As the mean density of WFT per bud and per sticky card increased, the RV values decreased (Figure 3.10a,b). RV values were high for both methods in orchard A following insecticide application on 21 April. However, RNP values were higher for the bud counts, suggesting that bud sampling resulted in greater sampling efficiency. This was due to the much greater mean search time for sticky cards, particularly as densities of WFT increased on cards in May.

**Figure 3.10a**



**Figure 3.10b**



**Figure 3.10a,b** Variation in Relative Variation (RV) values with increasing density of a) WFT per bud as calculated from sampling of nectarine buds for adult WFT and b) WFT per card as calculated from sampling of WFT from tree cards.

## Dispersion

Aggregation indices were calculated using Taylor's power law (Taylor, 1965) and Iwao's patchiness regression (Iwao, 1968) for adults at each of four stages of bud development: petal show, pink, bloom, and petal fall, and for larvae at petal fall (Appendix 3.3). For 1993, Iwao's patchiness regression gave a better fit to data (as assessed by  $r^2$  values) for adult counts at the pink stage and for larvae, whereas Taylor's power law gave a better fit for the bloom and petal fall counts. For 1994, Iwao's regression gave a better fit for the petal show, pink, late bloom, and petal fall counts, and Taylor's power law for the bloom counts of adults and for larvae. We did not have adequate data points for petal show in 1993. Regressions for similar bud development stages were compared over the two years, and if slopes were not found to differ significantly, data were pooled. Thus, data were pooled for the bloom, late bloom and petal fall stages. Analysis of the parameters that gave the best fit using linear regression displayed that all regressions were significant (Table 3.4a). The slopes of each statistically significant regression were compared with a slope of 1 using post-hoc testing of regression coefficients (MGLH option in SYSTAT). Adult WFT at pink (for 1993 only), bloom (pooled data for 1993 and 1994) and larval WFT for 1993, each showed significantly aggregated distributions among trees, whereas adult WFT caught at petal show in 1994 had a slope  $\beta$  significantly less than 1, which is generally not defined. Adult and larval WFT caught at all other bud developmental stages appeared to be randomly dispersed (Table 3.4b).

The within-tree dispersion of larvae (Table 3.4c) appeared to be better explained by the coefficients of Iwao's regression ( $F=82.646$ ,  $df=1,6$ ,  $P=0.000$ ). The slope of this regression did not differ significantly from a slope of  $b=1$  ( $F=0.018$ ,  $df=1,6$ ,  $P=0.898$ ), suggesting that larvae were randomly distributed within trees.



**Table 3.4a** Regression statistics for Taylor's Power law/Iwao's patchiness regression (see text) for the numbers of adults per bud for all orchards combined at the different stages of bud development: petal show 1994, pink 1993, pink 1994, bloom (pooled for both years), late bloom (pooled for both years) and petal fall (pooled for both years), and for larval density for 1993 and 1994.

| <b>Bud stage</b>       | <b>a</b> | <b>b</b> | <b>r<sup>2</sup></b> | <b>F</b> | <b>df</b> | <b>P</b> |
|------------------------|----------|----------|----------------------|----------|-----------|----------|
| <b>petal show 1994</b> | -0.79    | 0.58     | 0.38                 | 8.114    | 1,13      | 0.014    |
| <b>pink 1993</b>       | -0.91    | 1.37     | 0.97                 | 344.371  | 1,10      | 0.000    |
| <b>pink 1994</b>       | -0.93    | 1.08     | 0.97                 | 345.094  | 1,8       | 0.000    |
| <b>bloom</b>           | -0.52    | 1.40     | 0.72                 | 55.193   | 1,22      | 0.000    |
| <b>late bloom 1994</b> | -0.82    | 0.93     | 0.82                 | 36.632   | 1,8       | 0.000    |
| <b>petal fall</b>      | -0.88    | 1.16     | 0.69                 | 85.066   | 1,38      | 0.000    |
| <b>larvae 1993</b>     | -1.09    | 1.50     | 0.93                 | 240.139  | 1,18      | 0.000    |
| <b>larvae 1994</b>     | -0.53    | 1.08     | 0.86                 | 185.775  | 1,30      | 0.000    |

**Table 3.4b** Statistics for the comparison of the slopes of the above regressions (table 4a) with a slope of 1.

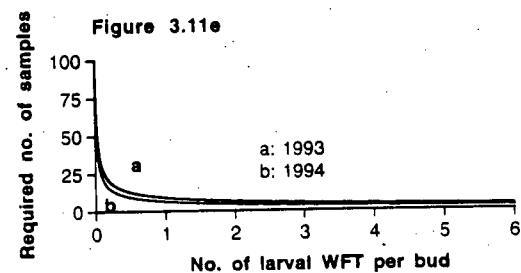
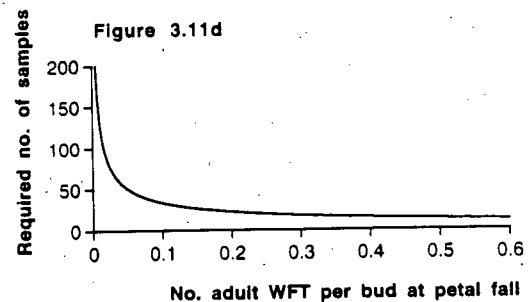
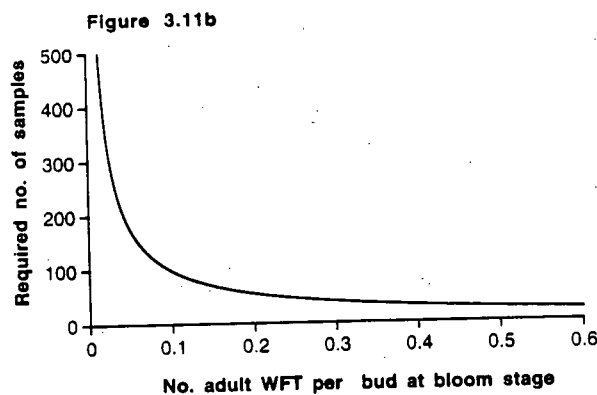
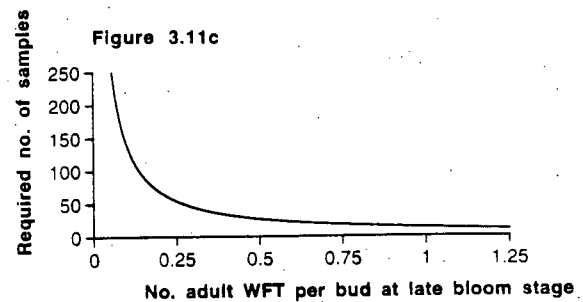
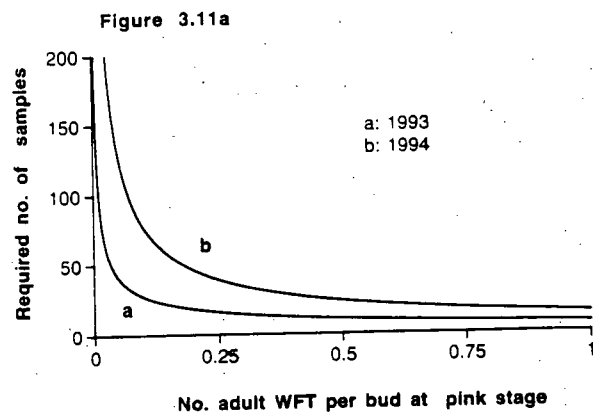
| <b>Bud stage</b>           | <b>F</b> | <b>df</b> | <b>P</b> |
|----------------------------|----------|-----------|----------|
| <b>petal show 1994</b>     | 2235.536 | 1,13      | 0.000    |
| <b>pink 1993</b>           | 23.356   | 1,10      | 0.001    |
| <b>pink 1994</b>           | 1.699    | 1,8       | 0.229    |
| <b>bloom (pooled)</b>      | 4.521    | 1,22      | 0.045    |
| <b>late bloom 1994</b>     | 0.915    | 1,8       | 0.367    |
| <b>petal fall (pooled)</b> | 1.598    | 1,38      | 0.214    |
| <b>larvae 1993</b>         | 26.928   | 1,18      | 0.000    |
| <b>larvae 1994</b>         | 0.911    | 1,30      | 0.348    |

**Table 3.4c** Within orchard dispersion for orchard C for larvae only in 1994. Means given are on a per bud basis.

| Life stage | Means range | Taylor's power law |      |                | Iwao regression |      |                |
|------------|-------------|--------------------|------|----------------|-----------------|------|----------------|
|            |             | a                  | b    | r <sup>2</sup> | a               | b    | r <sup>2</sup> |
| Larvae     | 0.9-2.68    | -0.78              | 1.01 | <b>0.25</b>    | -0.77           | 1.02 | <b>0.93</b>    |

Using these data we determined the required sample size of buds needed for a precision level of 0.25 for adults at each of the pink, bloom and petal fall stages as well as for larvae (Figures 3.11a-e). It is apparent that at low densities of WFT per bud, sampling 12 buds from 8-15 trees is not sufficient for this precision level. Only for larvae were the sample sizes even close to adequate.

Dispersion of WFT among the tree sticky cards was better explained by Iwao's regression rather than Taylor's Power Law in almost all cases (Appendix 3.4). Thus, we analysed the coefficients for Iwao's regression using linear regression analysis for each date for every orchard. All regressions were significant except for the first collection of sticky cards from orchard A (on 18 April) and from orchard I (on 23 April) (Appendix 3.5a). Analysis of the slopes for the statistically significant regressions showed that only in orchard A on 3 May, and in orchard I on 1 and 5 May were the slopes significantly different from 1 (Appendix 3.5b). Thus, in general, throughout the period of bud development, WFT were randomly distributed on the sticky cards, although WFT showed a more aggregated distribution within trees in orchard I throughout bloom, and in orchard A after the bloom period had ended and the emergence of the first generation had begun.



**Figure 3.11a-e** The required number of samples as suggested by Iwao's patchiness regression/Taylor's power law, for adult WFT in a) pink stage buds (1993 & 1994), b) bloom stage buds (for 1993 & 1994 pooled), c) late bloom buds (for 1993 & 1994 pooled), and d) petal fall buds (for 1993 & 1994 pooled), and larval WFT in e) petal fall (for 1993 & 1994).

## Egg-laying

### *I Exclusion methods:*

1993: The results from the exclusion experiment could only be statistically analysed for two of the orchards since aphid damage resulted in loss of most of the caged fruit in orchard I. Fruit from each treatment and control were rated for damage on 29 May for orchard C and G, and on 1 June for orchard I. In addition, a total of 25 fruit was taken from each of the four trees used for the experiments in each orchard and rated for damage on 3 June, 1 July and 1 June, for orchards C, G, and I, respectively. There was no significant difference in mean fruit damage for any period of caging (Orchard C:  $F=0.849$ ,  $df=3,15$ ,  $P=0.489$ ; Orchard G:  $KW=3.407$ ,  $df=3$ ,  $P=0.333$ ) (Table 3.5). However, in orchard G, mean damage tended to be greatest for cages under treatment A, which had been placed over buds from dormancy until full pink, (mean =4.55) followed by treatment B, which had been placed over buds from dormancy until bloom, (mean =3.06), and finally by treatment C, which had been placed over buds from dormancy until petal fall, (mean =2.73). Thus, most damage tended to take place during the period between pink and bloom. In orchard C, however, there was no reduction in damage under treatments A and B (mean damage, 4.4 and 4.5, respectively), although those cages under treatment C had reduced damage (mean =3.2). Fruit from control cages appeared to have lower damage levels than was found on uncaged fruit in orchard C but the opposite situation prevailed in orchard G, making conclusions of how open cages affect oviposition activity impossible.

**Table 3.5** Damage levels for each caging treatment, A, B and C in orchards C, G and I.

| Orchard | Treatment  |            |            |            | Orchard mean |
|---------|------------|------------|------------|------------|--------------|
|         | A          | B          | C          | Control    |              |
| C       | 4.39(0.43) | 4.54(0.43) | 3.04(0.50) | 3.21(0.47) | 3.66(0.38)   |
| G       | 4.55(0.27) | 3.06(0.34) | 2.73(0.78) | 4.11(0.59) | 2.93(0.31)   |
| I       | 5.55(0.38) | 4.27(0.50) | 4.42(0.98) | N/A        | 5.51(0.21)   |

A potential source of error in this experiment is in the timing of cage placement over buds- if cages were put out too late, there may already have been thrips present overwintering in or around the buds, which may have been caged inside with the buds. In addition, it is possible that some egg laying had already taken place over the winter or early in the year (i.e. before end of March) as thrips began to emerge and slowly became active. The information that most suggests that there has been some error in this experiment is the fact that buds caged under treatment A (i.e. over the period of dormancy to pink) tended to have greater damage levels on fruit than the mean for each of the orchards, even though these were not significant differences. This is difficult to interpret since any effect of caging such as attraction of females to the white mesh or containment of WFT overwintering alongside buds within cages, under treatment A, should be amplified in buds under treatments B and C which were caged for much more extensive periods of time. Observer bias can also be ruled out since the rating of fruit damage was done without prior knowledge of the treatment group. However, the means for treatments A, B, and C, as well as the control, were based on damage estimation from much smaller numbers of fruit than was the orchard mean. In the case of orchards C and G, the damage estimation for the orchard was carried out at a later date than for the treatments. In these cases, some damaged fruit may have dropped from the tree as a result of poor fruit set, and thus the damage level appears lower when assessed at the later dates. In orchard I when fruit damage was rated at the same time for both the caging treatments (plus control) and the other fruit on the trees, there does not appear to be the same difference in damage levels between the treatments and the orchard as a whole.

Even if some egg-laying had taken place in the early spring prior to caging, these results still suggest that further egg laying is taking place throughout bud development and thus it appears that egg-laying occurs over a long period of time and not in a single peak.

1994: Buds were caged much earlier in 1994 and the branches were sprayed with dormant oil prior to caging with the aim of destroying any aphid eggs, and possibly overwintering WFT. We expected that buds exposed during a particular window (e.g. buds exposed from early to late petal show) would be the first to contain larvae, which would indicate that thrips did not oviposit until this stage. However, we found larvae in all cages. This indicates that either 1) thrips are overwintering close to buds, 2) thrips are able to enter through tiny cracks in the cages or 3) thrips are attracted to the white mesh of the Nytex and oviposit through this into the bud tissue below. Our results were not consistent among orchards, thus comparisons are difficult to make. The bulk of eggs in orchards E and I were laid during the early stages of bud development, from white swell throughout pink, with little accumulation during bloom and petal fall. In orchard B, which had higher densities of WFT in general, eggs were laid equally throughout all the different developmental stages (Table 3.6a,b). In all orchards, however, a substantial number of larvae were found in buds that were caged from the white swell stage throughout bud development, which would suggest that egg-laying is taking place in the very early spring or even over the winter months on warm days.

**Table 3.6a** Numbers of larvae per bud collected from orchards B, F and I for each of five different caging regimes. Numbers of larvae are expressed per day that cages were open. Standard errors are given in parentheses.

| <b>Orchard</b> | <b>pc/petal<br/>show</b> | <b>Late petal<br/>show</b> | <b>Pink</b> | <b>Bloom</b> | <b>Petal fall</b> |
|----------------|--------------------------|----------------------------|-------------|--------------|-------------------|
| <b>B</b>       | 0.96(0.10)               | 2.5(1.38)                  | 1.94(0.72)  | 0.74(0.36)   | 0.25(0.17)        |
| <b>F</b>       | 0.49(0.43)               | 1.88(1.88)                 | 0.16(0.08)  | 0.11(0.05)   | 0.00(0.00)        |
| <b>I</b>       | 0.31(0.10)               | 0.13(0.03)                 | 0.02(0.02)  | 0.05(0.03)   | 0.08(0.08)        |

**Table 3.6b** Numbers of larvae per bud collected in orchards B, F and I for each of five different caging regimes. Numbers of larvae are not expressed per day but as a total per bud for the particular developmental period with which caging coincided. Standard errors are given in parentheses.

| Orchard  | ws/pc  | pc/petal<br>show | Late<br>petal<br>show | Pink   | Bloom  | Petal fall |
|----------|--------|------------------|-----------------------|--------|--------|------------|
| <b>B</b> | 1.84   | 6.70             | 5.00                  | 5.82   | 4.46   | 2.25       |
|          | (0.17) | (0.70)           | (2.75)                | (0.50) | (2.21) | (1.50)     |
| <b>F</b> | 11.27  | 3.39             | 3.13                  | 0.47   | 0.95   | 0.00       |
|          | (3.99) | (3.03)           | (1.39)                | (0.24) | (0.42) | (0.00)     |
| <b>I</b> | 0.13   | 1.88             | 0.25                  | 0.07   | 0.38   | 0.33       |
|          | (0.13) | (0.13)           | (0.25)                | (0.03) | (0.19) | (0.33)     |

## II Egg-counts by microscope

Eggs were apparent within buds from the time that trees were coming out of dormancy (Table 3.7). Despite high variability among buds, there were significantly greater numbers of eggs laid in buds in orchard B than orchard J during the white swell/pink colour ( $T = 2.504$ ,  $df=19$ ,  $P=0.022$ ) early petal show/petal show ( $T=3.477$ ,  $df=27$ ,  $P=0.002$ ) and full pink ( $T=3.175$ ,  $df=38$ ,  $P=0.003$ ) stages. We could not statistically compare the proportions of buds infested with eggs, but differences between the two orchards were not apparent. Damage levels in the two orchards varied similarly to the densities of eggs with lower damage levels in orchard J (mean damage:  $2.83 \pm$  SE of 0.29) than in orchard B (mean damage:  $4.17 \pm$  SE of 0.35).

Buds were pooled into vials of ethanol and, for the bloom stage, the petals did not remain attached to the rest of the buds, thus these egg counts could not be attributed to a per bud basis (thus we cannot calculate the standard error of the mean for these counts). There were no significant differences in egg densities among buds of the white swell, early petal show and pink stage in orchard J ( $\log(x+1)$  transformed data:  $F=0.796$ ,  $df=2,48$ ,  $P=0.796$ ). There were also no differences in the density of eggs among buds of the pink colour, early petal show and pink stages in orchard B ( $F=0.894$ ,  $df= 2,36$ ,  $P=0.418$ ).

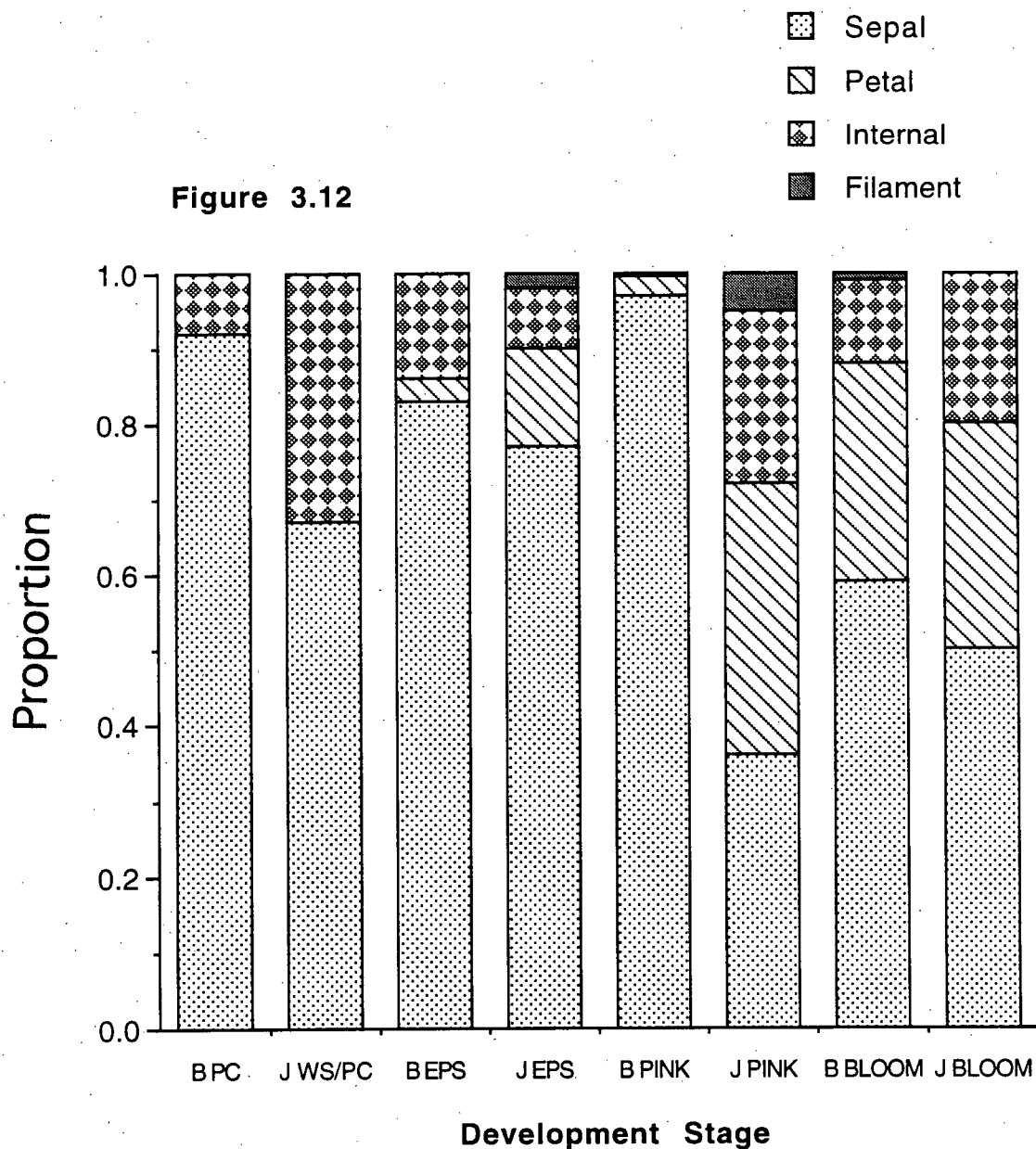
This would suggest that there is little or no accumulation of eggs over the bloom period, with most eggs laid early in the spring as the trees come out of dormancy. However, buds at the pink and bloom stages have often lost some of the sepals as they develop, thus new eggs laid on the internal bud and petal tissues may merely replace those lost, such that we did not see an increase in overall density. Almost all buds had eggs laid within them: however not all buds were found to contain larvae at petal fall, and thus there is clearly some egg mortality throughout development. The drawback of this technique is that it is impossible to determine which eggs are actually viable.

**Table 3.7** Proportion of buds with eggs and the mean number of eggs per bud for each of several stages of nectarine bud development in orchards B and J in 1994.

| Orchard | Bud stage                   | Proportion of buds with eggs | Mean no. eggs per bud | SEM for eggs per bud |
|---------|-----------------------------|------------------------------|-----------------------|----------------------|
| B       | pink colour                 | 0.91                         | 24.33                 | 6.71                 |
| B       | early petal show            | 0.86                         | 33.93                 | 7.50                 |
| B       | pink                        | 0.77                         | 21.93                 | 6.37                 |
| B       | bloom                       | 1.0                          | 20                    | N/A                  |
| J       | white swell/<br>pink colour | 0.54                         | 7.33                  | 3.14                 |
| J       | early petal show            | 0.93                         | 6.5                   | 1.38                 |
| J       | pink                        | 0.83                         | 5.48                  | 1.38                 |
| J       | bloom                       | unknown                      | 7                     | N/A                  |

Location of eggs laid varied dependent upon stage of development of the bud (Figure 3.12). In the swelling buds that were dissected at the stage just past dormancy, eggs were only found on the sepal tissue. On later bud stages, eggs were laid on sepal tissues, petals, filaments as well as the thicker, internal bud tissue that had not yet differentiated into petals. Eggs were laid in much lower numbers on petal and filament





**Figure 3.12** The proportion of eggs located in each of four positions- on sepals, petal tissues, internal bud tissues or on the filaments as shown by dissection of each of four different nectarine bud developmental stages: pink colour (pc) or white swell/pink colour (ws/pc), early petal show (eps), pink stage and bloom stage in orchards B and J.

tissue than on sepal and internal tissues and few eggs were laid on petal tissue prior to full bloom.

### **Assessment of thrips damage to ovaries**

Damage to buds was not discernible until the late bloom/early petal fall stage (Table 3.8). In orchard C, 6 % of pre-bloom buds had slight markings that may be attributable to oviposition activity, and a further 5% of buds had a large hole in the ovary or in the side of the husk (of unknown origin). At early petal fall (14 April), larvae were present within buds but bud damage was not yet apparent. This is not surprising since the minute first instar larvae were present primarily on filaments at that time. Damage was clearly apparent by mid petal fall (19 April), however, when minute russetting was visible on 34% of buds. By 23 April, 88% of buds showed some level of russetting. By 27 April, 100% of buds showed russetting in orchard C. On this date russetting was apparent even in buds without any larvae present, suggesting that larvae had either died or already dropped to the ground to pupate. Fruit damage in this orchard was rated on a scale from 1-7, thus we regrouped the damage categories from 1-5 so that damage levels could be compared throughout the development of the fruit. Damage levels were lower in July than in May, no doubt the result of natural fruit drop and manual fruit thinning but this orchard still received unacceptably high levels of damage.

**Table 3.8** Damage levels in buds taken from orchard C at various stages of development between early petal show and medium sized fruit.

| Bud stage        | Date     | Proportion buds damaged | Mean damage rating | n   |
|------------------|----------|-------------------------|--------------------|-----|
| Early petal show | April    | 0.00                    | 1.00               | 25  |
| Pink             | April    | 0.08                    | 1.08               | 25  |
| Bloom            | April    | 0.04                    | 1.08               | 25  |
| Early Petal fall | 14 April | 0.00                    | 1.00               | 50  |
| Mid petal fall   | 19 April | 0.34                    | 1.56               | 50  |
| Late petal fall  | 23 April | 0.88                    | 3.46               | 50  |
| Late petal fall  | 27 April | 1.00                    | 4.24               | 50  |
| Fruit 1" long    | 19 May   | 0.98                    | 4.64               | 159 |
| Fruit 2.5" long  | 11 July  | 0.89                    | 3.50               | 104 |

### Variety effects

For all variety comparisons, the densities of adults per tree were too low to allow statistical comparison. In both 1993 and 1994, densities of larvae in orchard H did not differ among varieties Independence and Flavourtop ( $F=0.51$ ,  $df=1,6$ ,  $P=0.502$  for 1993;  $F=5.07$ ,  $df=1,6$ ,  $P=0.065$  for 1994). In 1993 damage was higher in trees of variety Flavourtop in orchard H than in trees of variety Independence ( $F=6.13$ ,  $d=1,6$ ,  $P=0.048$ ) but in 1994, no significant differences were found ( $F=0.82$ ,  $df=1,6$ ,  $P=0.41$ ) (Table 3.9). For both 1993 and 1994, there appeared to be no difference in abundance of larvae or severity of damage in trees of either variety Redgold or Fantasia in orchard I (Larvae,  $F=3.78$ ,  $df=1,13$ ,  $P=0.074$  for 1993,  $F=0.07$ ,  $df=1,6$ ,  $P=0.81$  for 1994; Damage:  $F=2.36$ ,  $df=1,13$ ,  $P=0.15$  for 1993,  $F=0.00$ ,  $df=1,16$ ,  $P=0.996$  for 1994) (Table 3.9). In orchard J in 1993, however, there were significant differences in larval abundance and damage levels among trees of varieties HW106, Harblaze, Earliscarlet and Early Sungrand (Larvae:  $F=9.62$ ,  $df=3,8$ ,  $P=0.005$ ;  $\log(x+1)$  transformed data for damage:  $F=17.09$ ,

df=3,9, P=0.000) (Table 3.9). Post-hoc tests identified that larval abundance was highest in Early Sungrand, followed by varieties Harblaze and HW106, with lowest levels in trees of the variety Earlisscarlet. Damage levels were highest in the variety Early Sungrand, followed by HW106, then Harblaze, and lowest levels in Earlisscarlet. Finally, there were no significant differences in either abundance of larvae or damage levels among trees of variety Rubygold, Early Sungrand, Crimsongold or Redgold in orchard K in 1994 (Larvae: F=1.35, df=3,11, P=0.31; Damage: F=2.14, df=3,11, P=0.15) (Table 3.9).

**Table 3.9** Mean levels of damage per tree for each of variety comparison made in orchards H, I J and K over 1993 and 1994. SEM are given in parentheses.

| Orchard  | Year | Varieties           |                       |                       |                      |
|----------|------|---------------------|-----------------------|-----------------------|----------------------|
| <b>H</b> |      | <b>Independence</b> | <b>Flavourtop</b>     |                       |                      |
|          | 1993 | 2.46(0.29)          | 2.88(0.16)            |                       |                      |
|          | 1994 | 1.49(0.57)          | 1.83(0.44)            |                       |                      |
| <b>I</b> |      | <b>Fantasia</b>     | <b>Redgold</b>        |                       |                      |
|          | 1993 | 5.01(0.32)          | 4.15(0.50)            |                       |                      |
|          | 1994 | 2.16(0.26)          | 2.15(0.28)            |                       |                      |
| <b>J</b> |      | <b>HW106</b>        | <b>Harblaze</b>       | <b>Early Sungrand</b> | <b>Earli-Scarlet</b> |
|          | 1993 | 5.11(0.65)          | 3.67(0.16)            | 5.52(0.29)            | 2.35(0.23)           |
| <b>K</b> |      | <b>Rubygold</b>     | <b>Early Sungrand</b> | <b>Crimson-gold</b>   | <b>Redgold</b>       |
|          | 1994 | 6.88(0.06)          | 6.75(0.11)            | 6.05(0.31)            | 5.84(0.64)           |

### Female Dispersal

Upon examination of the original forty blooms under UV light in the laboratory, we found that in only three blooms were fluorescent females still present. This suggests that

there is a great deal of movement by females and that they do not remain in a bloom for any length of time. Conditions over the course of this trial were warm and sunny.

### 3.4 DISCUSSION

Direct sampling methods, although time consuming, are probably the best methods for detection of thrips populations within nectarine crops. Sticky cards located on posts do not serve as an efficient early warning mechanism, possibly because the temperatures required for flight are higher than those required for local movements on areas of bark and around buds on trees and oviposition. Examination of buds showed that eggs were laid when buds were just beginning to swell, yet WFT were not caught on sticky cards until the petal show stage. In addition, WFT were not always found on sticky cards before they were caught in buds. Non-invasive sampling methods, such as use of beating boards, visual inspection and flicking of buds were much less effective than invasive sampling. WFT adults and larvae are well protected inside the husk of the nectarine flower and thus visual inspection of flowers to estimate WFT density was impossible since the insects are hidden from view. Similarly, beating and flicking methods were extremely unreliable. Flicking may be a possible and rapid sampling method in non-husked flowers, such as apple (Terry and DeGrandi-Hoffman, 1988), but cannot be used for nectarine.

Whole plant sampling is not an option in this crop, thus we could not compare our density estimates with this type of absolute estimate. However we were able to compare two of our relative estimates: field and laboratory counts of densities of adult and larval WFT per bud. On-site estimations of WFT abundance appeared to underestimate both adult and larval density, particularly in the case of the pale morph of WFT, which is harder to see in bright light than the darker, larger-sized dark morph. Adult WFT appear to fly off buds when they are disturbed, which no doubt explains the underestimation of field counts. Shortly after larval hatch, larvae are transparent and cannot be seen with the naked eye. In the field with bright sunshine, minute first instars are not easily seen with a hand lens. A previous study found that first instar larvae are mainly located among the filaments (Pearsall, chapter 2). This protected situation makes them even more difficult to see.

Thus, field surveys have the potential to miss the time of larval hatch as well as to underestimate larval abundance. Within a few days larvae become a creamy white colour from eating plant tissue. Once they have reached the second instar stage they are visible by eye, and are generally located in more damaging positions on the fruit surface. Damage appears to occur very quickly at this point, and thus if one waits to apply treatments until after larvae are clearly visible, it is likely to be too late to prevent damage to the fruit.

In greenhouses, catches on sticky traps are affected by flight activity of thrips, the population size of thrips and the attractiveness of the trap relative to its environment, such as the type of surrounding crop plants, or the colour of the background of the trap (Brodsgaard, 1993; Berlinger *et al.*, 1993; Gillespie and Vernon, 1990). In the field, factors that affect the attractiveness of traps include the trap density, crop stage, orientation of the trap and light intensity whereas temperature, humidity, light intensity and physical disturbance all influence thrips activity. We might expect that the sticky traps would not show the same trends as direct bud sampling since the traps may catch not only the trivial fliers moving within a field but also migratory forms that are moving into or across the field (Byrne and Houck, 1990). We might also expect divergence in the estimates of density as abundance varied. For example, sticky cards and direct bud sampling may show similar trends in patterns of population density when the adult population level is low but as density increases this may lead to increased adult flight activity and movement across the field which may bias the accuracy of sticky cards.

Shipp and Zariffa (1991) found that the number of adults in pepper flowers was better correlated with the total number of adult WFT on the plant than were larval leaf counts and therefore they suggested that flower sampling would be the most cost effective method of monitoring population densities. Unfortunately, we were unable to make such comparisons, since we were unable to remove all the buds from a tree. However, we were able to assess the accuracy of the estimates of abundance as provided by bud sampling and sticky cards. Although relative variation levels were generally lower for sticky cards than

for bud sampling, the latter were generally more efficient due to the lower cost in terms of the time taken to count adults in buds. Previous work has suggested that the location of trees within orchards, the time of day, and the location of the buds within trees do not appear to have any impact on density estimates (Pearsall, chapter 2). It does appear, however, that a greater number of trees need to be sampled to provide a more precise estimate of mean abundance. Palumbo *et al.* (1995) found that sticky traps were less accurate than a direct method (Leafturn) and Handvac sampling for sampling of whiteflies, but was the most efficient method statistically. But they also found that the sticky traps took much longer to count. Naranjo *et al.* (1995) in a comparison of sampling methods for the sweetpotato whitefly (*Bemisia tabaci* Genn.) found that although sticky cards were useful for monitoring and detection of movement and regional population levels, that they were inefficient as sampling tools in comparison with more direct sampling methods (plant sampling and tapping). On apple and cotton, the spatial abundance of WFT is directly related to the location of open blooms, to which WFT are highly attracted (Pickett *et al.*, 1988; Terry and DeGrandi-Hoffman, 1988). In greenhouse cucumber, the recommended sampling methods for WFT are the use of blue sticky cards together with leaf samples (Gillespie and Vernon, 1990; Steiner, 1990).

In conclusion, sticky cards would not work as an early warning system for growers and, because they are expensive to use and more time-consuming to count than bud sampling, the latter method is probably more favourable.

We did not find any clear relationship between adult counts on sticky cards and either larval densities per tree or damage levels per tree. Schmidt and Frey (1995) suggested that there is often low correlation between sticky trap counts and the damage seen on plants or the pest population densities. However, in cucumber, Brodsgaard (1993) found moderate correlations ( $r^2=0.47$ ) between leaf and trap counts and Shipp and Zariffa (1991) found good correlations of  $r^2=0.68-0.92$  between whole plant and trap counts in sweet pepper.



In addition, we found that in almost all cases, knowledge of the number of adults per bud on a particular tree did not enable us to predict either future larval or damage levels. This is similar to other studies. Steiner (1990) also found that there was little correlation between WFT density on plants and damage to greenhouse cucumber fruit. Naranjo *et al.* (1995) in a study of the sweetpotato whitefly found that correlations relating adult abundance to immature abundance in cotton fields were highly variable among years and sites, and that the correlation coefficients were generally reduced after insecticide applications. In the Dry Central Interior, insecticide applications of various types were made in all orchards in 1993, and in all except for orchards C, F, K and L in 1994. Salguero Navas *et al.* (1991b) found that the relationship between the number of scars per tomato fruit caused by WFT oviposition and density per flower of WFT was quadratic, but that the amount of variation explained by the model was very low. The effects of *T. tabaci* Lindeman in yellow onion fields were also found to be best described by non-linear models (Fournier *et al.*, 1995). The authors in this study found that "pressure" from thrips on plants was best described by the use of cumulative thrips days per plant. However, they were able to use the models in a predictive fashion, and did produce calculations of economic damage thresholds, although they suggested that onion plant damage is not simply a function of thrips density, but also of additional factors, such as climate, type of damage, part of the plant damaged, timing of damage, and other environmental factors such as irrigation regimes.

Damage thresholds are clearly very low for WFT and, in the case of larvae, there can be no tolerance of any number of larvae since even a single one may result in serious damage. Because of the high egg load and high mobility of this insect, it is not surprising that a few adult females can result in much more serious damage than would be expected if they remained resident within a single flower for all egg-laying. Results of the fluorescent marking of females suggested that females do not tend to remain resident within a bloom for very long. In 1993, no more than one adult female thrips was ever recovered from a

sample of 96 buds from orchards G and H. These samples were taken every four days for more than two weeks. However, in these same orchards, on-site estimations showed that approximately 35% of the flowers contained larvae at petal fall. Only on an orchard scale did damage show any relationship with larval load. The reason that this relationship is not apparent when expressed on a per tree basis within orchards may be due to the fact that the amount of damage depends not only on larval density, but also the rate of development of the nectarine buds. At higher temperatures, husk-fall occurs more rapidly, at which time, larvae are no longer protected in buds and also fall to the ground. Larval residence time in buds will therefore be shorter which may reduce damage. Because of micro climate effects, different trees may develop at different rates from petal fall to husk drop within an orchard. Steiner (1990) suggested that the threshold level of WFT in vegetables such as cucumbers depends on the rate of growth of the shoot, with slow growth generally resulting in increased fruit damage.

Because of the poor predictive relationship between both the density of adults on trees or on sticky cards within trees and the subsequent density of larvae per tree, and the lack of relationship between adults or larvae and damage, it is impossible to determine threshold densities of WFT in nectarine. Larvae cause the damage to the fruit, but it is necessary to use adult densities as the early warning stage, since often the time period between first detection of larvae and fruit damage is too short for growers to be able to adequately protect their crops.

Adult and larval WFT were aggregated among nectarine trees during some stages of fruit development, but randomly dispersed during most stages, and larvae appeared to be randomly distributed within buds. We found also that WFT were randomly dispersed among sticky cards that were placed within nectarine tree canopies. In tomato flowers, adult and larval WFT were found to be aggregated, with larvae showing greater levels of aggregation than adults (Salguero Navas *et al.*, 1994). Unfortunately we did not have sufficient data on the dispersion of adults among nectarine flower buds. Steiner (1990)

also found that *F. occidentalis* adults and larvae were aggregated on leaves of greenhouse cucumber, with higher levels of aggregation of larvae than adults. Similarly, Shipp and Zariffa (1991) found aggregated distributions of WFT in flowers of greenhouse sweet peppers. Other species of thrips have shown different patterns of aggregation: adult *Megalurothrips sjostedi* (Trybom) are randomly distributed in cowpeas at low densities, whereas both larvae and adults have aggregated distributions at higher densities. I sampled only the buds and blossoms of nectarine for WFT since preference for flowers has already been well documented for this insect (e.g. Pickett *et al.*, 1988; Yudin *et al.*, 1988; Higgins, 1992).

Female western flower thrips appear to be laying eggs on nectarine tissues earlier than has been generally believed. Kourmadas *et al.* (1982) showed with the use of exclusion cages that nectarines are most sensitive to damage by *Frankliniella intonsa* (Trybom) and *Taeniothrips meridionalis* Priesner between the commencement of blooming until calyx drop. However, I found that although laborious, egg counts were a more accurate method of elucidating both when and where eggs are laid than the use of exclusion cages. The general consensus in this region prior to this study was that WFT were most likely laying eggs during the pink and bloom stages, and that larvae were present at petal fall. However, the density of eggs did not differ among the different stages of bloom, suggesting that the bulk of eggs were laid early on at the white swell/pink colour stage when buds have swollen and the outer sepal tissue has begun to turn pink. These eggs were being laid when WFT would not be caught on sticky cards because temperatures are too low for flight, and when WFT would likely not be found within bud samples because of low activity and density levels. It is possible that some eggs were laid even prior to bud swelling, possibly over the winter. This still remains to be determined. Western flower thrips overwinter on the nectarine trees (Pearsall, chapter 2) and as the tree bark is warmed on sunny days during the winter, it is possible that they may become slightly active and lay eggs in the dormant buds. Thrips are first found *inside* buds by the early petal stage but

they are active *on* buds prior to this time. In fact, emergence of WFT from the ground and from within bark on the trees was occurring while trees were still in the dormant stage (Pearsall, chapter 2 ).

Eggs were laid primarily on the sepal tissue before buds had opened. Young larvae were found mainly on the filaments after hatching which may be expected if they are crawling into the husk from the outside of the bud (Pearsall, chapter 2). Few eggs were found on petals which seems to be a sensible strategy considering that the petals will fall from the buds before larval hatch. There were also very few eggs laid on the filaments, which also dry up over the period of petal fall, and do so particularly quickly on hot days. This oviposition activity by females did not appear to lead to damage of the fruit, which may be attributed almost entirely to larval feeding.

Results from a study of WFT oviposition in apple, cv. Granny Smith, buds showed that most eggs were laid on buds by the early-pink to early-bloom state, with little or no increase in egg density later in the bloom period. Clusters maturing later in bloom had few to no eggs (Terry, 1991). This author found that petal fall clusters had a significantly greater proportion of buds with eggs and higher egg densities than pink or open-blossom clusters. She suggested that these were from the accumulation of unhatched eggs laid during pink and early bloom states, since the duration of the egg stage is generally longer than the duration of the cluster stages, with eggs expected to hatch in 6-13 days at the bloom temperatures in the apple orchards (mean of 15-23°C), whereas bud clusters advanced from one stage to the next within 3-6 days with these temperatures. Eggs were also often laid on the sepals and stems of the apple buds (12-100% ) rather than around the ovary. She found that there was no relationship between egg densities and thrips densities, despite large differences in thrips densities among treatments and over years of the study. Other authors, for example, Yokoyama (1977) and Jensen (1973) have shown slightly positive to negative relationships between thrips densities and oviposition damage to grapes. We were not able to examine this relationship in nectarine, although we did find

higher densities of eggs in orchard B, which also had higher densities of adult thrips than were found in orchard J. Orchard B also had higher densities of larvae, higher proportions of buds infested with larvae and higher levels of damage than orchard J. Although densities of eggs in buds varied between zero and eighty, the densities of larvae per bud did not appear to exceed nine, (Pearsall, chapter 2), which suggests that there is substantial egg mortality or mortality of larvae hatching in the buds. Venables (1925) also found considerable numbers of eggs in apple buds in the Pacific Northwest.

Catches of WFT on the sticky cards within trees showed that there were large numbers of WFT active within trees after petal fall, as judged by the large peak in catches in mid-May in these orchards. This new generation may be laying eggs both on petal fall buds and on young leaf tissue (Pearsall, chapter 2 ) and may partially account for the fact that larvae were found within cages that were only opened at the petal fall stage in 1994.

In general, there appeared to be no differences in severity of damage among different varieties of nectarines within orchards. It appears that the location of an orchard, as well as climatic conditions, are probably more important to damage levels, with similar varieties exhibiting large differences in damage levels across orchards and across years (Pearsall, chapter 2, and unpublished data).

### 3.5 APPENDICES

**Appendix 3.1** Regression statistics for the catches of WFT on sticky cards versus a) first larval count, b) second larval count, c) peak larval count and d) damage per tree in orchards A,C, and I. Counts used are mean counts per tree for a total of eight trees per orchard.

| a) Regression statistics for first larval count |                             |            |       |       |                |        |     |       |
|---|-----------------------------|------------|-------|-------|----------------|--------|-----|-------|
| Orchard   | Sticky card collection date | Bud stage  | a     | b     | r <sup>2</sup> | F      | df  | P     |
| A   | 18/4                        | petal show | -0.65 | 0.57  | 0.94           | 99.642 | 1,6 | 0.000 |
| A   | 23/4                        | pink       | 4.89  | -0.11 | 0.13           | 0.917  | 1,6 | 0.375 |
| A   | 26/4                        | bloom      | 4.96  | -0.11 | 0.15           | 1.066  | 1,6 | 0.342 |
| C   | 22/4                        | petal show | 0.37  | 0.08  | 0.36           | 2.836  | 1,5 | 0.153 |
| C   | 26/4                        | pink       | 0.69  | 0.12  | 0.22           | 0.946  | 1,5 | 0.375 |
| C   | 1/5                         | bloom      | 1.26  | 0.06  | 0.19           | 1.137  | 1,5 | 0.335 |
| I   | 23/4                        | petal show | 0.27  | 0.01  | 0.01           | 0.046  | 1,4 | 0.840 |
| I   | 27/4                        | pink       | 0.22  | 0.01  | 0.05           | 0.203  | 1,4 | 0.675 |
| I   | 1/5                         | bloom      | 0.26  | 0.01  | 0.03           | 0.114  | 1,4 | 0.753 |

b) Regression statistics for second larval count

| Orchard | Sticky card collection date | Bud stage  | a    | b    | r <sup>2</sup> | F     | df  | P     |
|---------|-----------------------------|------------|------|------|----------------|-------|-----|-------|
| A       | 18/4                        | petal show | 2.18 | 0.10 | 0.24           | 1.933 | 1,6 | 0.214 |
| A       | 23/4                        | pink       | 1.04 | 0.05 | 0.23           | 1.824 | 1,6 | 0.226 |
| A       | 26/4                        | bloom      | 0.90 | 0.06 | 0.44           | 4.791 | 1,6 | 0.071 |
| C       | 22/4                        | petal show | 0.42 | 0.01 | 0.13           | 0.892 | 1,6 | 0.381 |
| C       | 26/4                        | pink       | 0.43 | 0.02 | 0.09           | 0.406 | 1,6 | 0.548 |
| C       | 1/5                         | bloom      | 0.49 | 0.01 | 0.10           | 0.642 | 1,6 | 0.454 |
| I       | 23/4                        | petal s    | 0.78 | 0.06 | 0.40           | 4.044 | 1,6 | 0.091 |
| I       | 27/4                        | pink show  | 0.82 | 0.05 | 0.38           | 3.666 | 1,6 | 0.104 |
| I       | 1/5                         | bloom      | 0.93 | 0.04 | 0.20           | 1.503 | 1,6 | 0.266 |

c) Regression statistics for peak larvae (Orchard I is excluded since the second larval count = peak larval count.

| Orchard | Sticky card collection date | Bud stage  | a     | b     | r <sup>2</sup> | F      | df  | P            |
|---------|-----------------------------|------------|-------|-------|----------------|--------|-----|--------------|
| A       | 18/4                        | petal show | -0.50 | 0.56  | 0.93           | 79.804 | 1,6 | <b>0.000</b> |
| A       | 23/4                        | pink       | 4.90  | -0.10 | 0.12           | 0.802  | 1,6 | 0.405        |
| A       | 26/4                        | bloom      | 4.93  | -0.10 | 0.12           | 0.839  | 1,6 | 0.395        |
| C       | 22/4                        | petal show | 0.32  | 0.08  | 0.17           | 4.490  | 1,6 | 0.078        |
| C       | 26/4                        | pink       | 0.58  | 0.12  | 0.33           | 1.191  | 1,6 | 0.317        |
| C       | 1/5                         | bloom      | 1.16  | 0.05  | 0.18           | 1.295  | 1,6 | 0.298        |



d) Regression statistics for damage

| Orchard | Sticky card collection date | Bud stage  | a    | b     | r <sup>2</sup> | F      | df  | P            |
|---------|-----------------------------|------------|------|-------|----------------|--------|-----|--------------|
| A       | 18/4                        | petal show | 4.73 | 0.05  | 0.09           | 0.563  | 1,6 | 0.482        |
| A       | 23/4                        | pink       | 5.17 | -0.01 | 0.02           | 0.1    | 1,6 | 0.763        |
| A       | 26/4                        | bloom      | 5.32 | -0.03 | 0.14           | 0.989  | 1,6 | 0.358        |
| C       | 22/4                        | petal show | 2.57 | 0.04  | 0.38           | 3.641  | 1,6 | 0.105        |
| C       | 26/4                        | pink       | 2.29 | 0.08  | 0.73           | 16.366 | 1,6 | <b>0.007</b> |
| C       | 1/5                         | bloom      | 2.60 | 0.05  | 0.73           | 15.799 | 1,6 | <b>0.007</b> |
| I       | 23/4                        | petal show | 4.34 | -0.03 | 0.02           | 0.104  | 1,6 | 0.758        |
| I       | 27/4                        | pink       | 4.21 | -0.01 | 0.00           | 0.027  | 1,6 | 0.876        |
| I       | 1/5                         | bloom      | 4.21 | -0.02 | 0.00           | 0.026  | 1,6 | 0.878        |

### Appendix 3.2 Regression statistics per orchard for the relationship between adult densities, larval densities and damage.

a) Regressions of pre-petal fall adult density versus larval density per tree for each orchard:

I) 1993: *pre-petal fall adult densities per tree regressed against the first, second & peak larval counts per tree.*

| Orch | First larval count |       |                |      |     |       | Second larval count |       |                |      |      |       | Peak larval count |       |                |      |     |       |
|------|--------------------|-------|----------------|------|-----|-------|---------------------|-------|----------------|------|------|-------|-------------------|-------|----------------|------|-----|-------|
|      | a                  | b     | r <sup>2</sup> | F    | df  | P     | a                   | b     | r <sup>2</sup> | F    | df   | P     | a                 | b     | r <sup>2</sup> | F    | df  | P     |
| A    | 2.08               | 31.52 | 0.82           | 27.9 | 1,6 | 0.002 | 1.66                | -4.13 | 0.13           | 0.92 | 1,6  | 0.376 | 2.16              | 31.19 | 0.83           | 28.4 | 1,6 | 0.002 |
| B    | 2.44               | -11.9 | 0.24           | 1.56 | 1,5 | 0.267 | 0.98                | 3.6   | 0.07           | 0.36 | 1,5  | 0.577 | 2.14              | -3.94 | 0.05           | 0.33 | 1,6 | 0.588 |
| C    | 1.39               | 9.48  | 0.05           | 0.28 | 1,5 | 0.618 | 0.36                | 3.96  | 0.18           | 1.31 | 1,6  | 0.297 | 1.11              | 12.16 | 0.09           | 0.56 | 1,6 | 0.483 |
| D    | 0.36               | 8.57  | 0.26           | 2.13 | 1,6 | 0.195 | 1.03                | -2.16 | 0.01           | 0.07 | 1,6  | 0.805 | 1.03              | 0.37  | 0.00           | 0.00 | 1,6 | 0.964 |
| E    | 0.04               | 19.96 | 0.38           | 3.57 | 1,6 | 0.108 | 0.59                | 0.87  | 0.05           | 0.30 | 1,6  | 0.606 | 0.53              | 14.3  | 0.27           | 2.22 | 1,6 | 0.187 |
| F    | 0.5                | 0.18  | 0.00           | 0.01 | 1,4 | 0.93  | 0.62                | 6.67  | 0.51           | 3.09 | 1,3  | 0.177 |                   |       |                |      |     |       |
| G    | 0.13               | 0.11  | 0.00           | 0.01 | 1,6 | 0.92  | 0.36                | -0.60 | 0.10           | 0.65 | 1,6  | 0.452 |                   |       |                |      |     |       |
| I    | 0.20               | 3.42  | 0.27           | 1.50 | 1,5 | 0.288 | 1.12                | 0.94  | 0.01           | 0.07 | 1,6  | 0.802 |                   |       |                |      |     |       |
| J    | 2.69               | -3.45 | 0.13           | 1.31 | 1,9 | 0.282 | 0.84                | 0.90  | 0.08           | 0.91 | 1,11 | 0.361 |                   |       |                |      |     |       |

II) 1994: pre-petal fall adult densities per tree regressed against the mean and peak larval counts per tree.

| Orch | Mean larval count |       |                |        |      | Peak larval count |       |       |                |        |      |              |
|------|-------------------|-------|----------------|--------|------|-------------------|-------|-------|----------------|--------|------|--------------|
|      | a                 | b     | r <sup>2</sup> | F      | df   | P                 | a     | b     | r <sup>2</sup> | F      | df   | P            |
| A    | 0.17              | 1.68  | 0.07           | 0.453  | 1,6  | 0.526             | 0.70  | 1.85  | 0.03           | 0.187  | 1,6  | 0.681        |
| B    | 4.09              | -2.97 | 0.07           | 0.417  | 1,6  | 0.543             | 6.93  | -5.67 | 0.07           | 0.479  | 1,6  | 0.515        |
| C    | 0.11              | 9.44  | <b>0.64</b>    | 10.851 | 1,6  | <b>0.017</b>      | 1.80  | 13.18 | <b>0.93</b>    | 74.792 | 1,6  | <b>0.000</b> |
| D    | 1.03              | 2.48  | 0.06           | 0.374  | 1,6  | 0.563             | 1.36  | 7.42  | 0.22           | 1.722  | 1,6  | 0.237        |
| E    | -0.83             | 13.07 | <b>0.76</b>    | 18.936 | 1,6  | <b>0.005</b>      | -0.61 | 13.92 | <b>0.76</b>    | 18.523 | 1,6  | <b>0.005</b> |
| F    | 3.44              | -1.37 | 0.01           | 0.056  | 1,4  | 0.825             | 3.44  | 4.98  | 0.19           | 0.922  | 1,4  | 0.391        |
| H    | 0.44              | 1.24  | 0.0.           | 0.154  | 1,6  | 0.708             | 0.70  | 1.19  | 0.01           | 0.071  | 1,6  | 0.798        |
| I    | -0.02             | 3.9   | 0.33           | 3.008  | 1,6  | 0.134             | -0.08 | 6.91  | 0.49           | 5.669  | 1,6  | 0.055        |
| J    | 0.83              | 0.38  | 0.00           | 0.032  | 1,10 | 0.862             | 1.7   | 0.01  | 0.00           | 0.000  | 1,10 | 0.998        |

b) Regressions of pre-petal fall adult density versus damage levels per tree for each orchard.

1) 1993: *pre-petal fall adult densities per tree regressed against mean damage levels per tree.*

| Orchard | a    | b      | r <sup>2</sup> | F     | df   | P            |
|---------|------|--------|----------------|-------|------|--------------|
| A       | 5.0  | 1.57   | 0.03           | 0.189 | 1,6  | 0.679        |
| B       | 3.54 | 0.3    | 0.00           | 0.003 | 1,6  | 0.96         |
| C       | 2.32 | 15.64  | 0.58           | 8.353 | 1,6  | <b>0.028</b> |
| D       | 2.91 | -5.8   | 0.05           | 0.324 | 1,6  | 0.059        |
| E       | 4.62 | -11.88 | 0.23           | 1.74  | 1,6  | 0.235        |
| F       | 2.77 | 1.75   | 0.02           | 0.1   | 1,4  | 0.768        |
| G       | 3.74 | -4.47  | 0.11           | 0.76  | 1,6  | 0.417        |
| I       | 5.13 | -16.58 | 0.47           | 5.181 | 1,6  | 0.063        |
| J       | 4.83 | -0.53  | 0.01           | 0.075 | 1,11 | 0.075        |

II) 1994: pre-petal fall adult densities per tree regressed against mean damage levels per tree.

| Orchard | a    | b      | r <sup>2</sup> | F     | df   | P     |
|---------|------|--------|----------------|-------|------|-------|
| A       | 1.65 | 0.98   | 0.15           | 1.069 | 1,6  | 0.341 |
| B       | 2.72 | 6.68   | 0.45           | 4.847 | 1,6  | 0.07  |
| C       | 6.24 | 0.6    | 0.03           | 0.177 | 1,6  | 0.689 |
| D       | 4.94 | -12.03 | 0.43           | 0.382 | 1,6  | 0.559 |
| E       | 4.69 | 3.79   | 0.23           | 1.782 | 1,6  | 0.23  |
| F       | 2.34 | 2.04   | 0.39           | 2.605 | 1,4  | 0.182 |
| H       | 1.18 | 7.75   | 0.50           | 5.008 | 1,5  | 0.075 |
| I       | 1.39 | 10.48  | 0.13           | 0.88  | 1,6  | 0.384 |
| J       | 2.35 | 5.22   | 0.1            | 1.112 | 1,10 | 0.316 |

c) Regressions of larval density versus damage levels per tree for each orchard:

I) 1993: larval densities (first, second and peak counts) per tree regressed against mean damage levels per tree.

|   | Orch first count |       |                |      |     |       | second count |       |                |      |      |       | peak count |       |                |      |     |       |
|---|------------------|-------|----------------|------|-----|-------|--------------|-------|----------------|------|------|-------|------------|-------|----------------|------|-----|-------|
|   | a                | b     | r <sup>2</sup> | F    | df  | P     | a            | b     | r <sup>2</sup> | F    | df   | P     | a          | b     | r <sup>2</sup> | F    | df  | P     |
| A | 4.82             | 0.07  | 0.07           | 0.46 | 1,6 | 0.521 | 6.01         | -0.65 | <b>0.67</b>    | 12.4 | 1,6  | 0.012 | 4.86       | 0.06  | 0.05           | 0.30 | 1,6 | 0.603 |
| B | 3.97             | -0.23 | 0.13           | 0.72 | 1,6 | 0.436 | 3.17         | 0.49  | 0.50           | 4.91 | 1,6  | 0.077 | 3.26       | 0.15  | 0.04           | 0.22 | 1,6 | 0.655 |
| C | 2.64             | 0.32  | 0.40           | 3.30 | 1,5 | 0.129 | 3.31         | -0.05 | 0.00           | 0.00 | 1,6  | 0.955 | 2.77       | 0.28  | 0.31           | 2.70 | 1,6 | 0.152 |
| D | 2.92             | -0.23 | 0.02           | 0.14 | 1,6 | 0.724 | 2.47         | 0.34  | 0.07           | 0.48 | 1,6  | 0.516 | 2.43       | 0.36  | 0.07           | 0.47 | 1,6 | 0.521 |
| E | 4.13             | -0.13 | 0.03           | 0.17 | 1,6 | 0.696 | 3.22         | 1.21  | 0.04           | 0.24 | 1,6  | 0.645 | 4.15       | -0.13 | 0.02           | 0.12 | 1,6 | 0.74  |
| F | 2.52             | 0.93  | 0.10           | 0.1  | 1,4 | 0.768 | 2.27         | 0.36  | 0.18           | 0.45 | 1,4  | 0.538 | 2.77       | 1.75  | 0.02           | 0.65 | 1,3 | 0.48  |
| G | 3.43             | 0.74  | 0.02           | 0.11 | 1,6 | 0.754 | 4.35         | -2.47 | 0.13           | 0.86 | 1,6  | 0.391 |            |       |                |      |     |       |
| H | 2.71             | -4.39 | 0.16           | 1.1  | 1,6 | 0.335 | 2.51         | 0.20  | 0.07           | 0.43 | 1,6  | 0.538 |            |       |                |      |     |       |
| I | 4.41             | -0.36 | 0.01           | 0.04 | 1,6 | 0.859 | 3.89         | 0.24  | 0.01           | 0.05 | 1,6  | 0.835 |            |       |                |      |     |       |
| J | 4.83             | -0.1  | 0.02           | 0.17 | 1,9 | 0.694 | 4.46         | 0.19  | 0.01           | 0.11 | 1,11 | 0.75  |            |       |                |      |     |       |

II) 1994: larval densities (mean counts and peak counts) per tree regressed against mean damage levels per tree.

| Orch | Mean count |       |                |       |      |       | Peak count |       |                |       |      |       |
|------|------------|-------|----------------|-------|------|-------|------------|-------|----------------|-------|------|-------|
|      | a          | b     | r <sup>2</sup> | F     | df   | P     | a          | b     | r <sup>2</sup> | F     | df   | P     |
| A    | 1.98       | 0.16  | 0.15           | 1.062 | 1,6  | 0.343 | 1.99       | 0.09  | 0.14           | 0.951 | 1,6  | 0.367 |
| B    | 6.02       | -0.54 | 0.39           | 3.835 | 1,6  | 0.098 | 5.78       | -0.28 | 0.35           | 3.178 | 1,6  | 0.125 |
| C    | 6.25       | 0.06  | 0.04           | 0.249 | 1,6  | 0.635 | 6.40       | 0.01  | 0.00           | 0.006 | 1,6  | 0.942 |
| D    | 3.46       | 0.37  | 0.06           | 0.363 | 1,6  | 0.569 | 3.41       | 0.26  | 0.07           | 0.404 | 1,6  | 0.549 |
| E    | 5.28       | 0.15  | 0.08           | 0.55  | 1,6  | 0.486 | 4.98       | 0.23  | 0.22           | 1.69  | 1,6  | 0.241 |
| F    | 2.44       | 0.15  | 0.30           | 1.679 | 1,4  | 0.265 | 2.18       | 0.15  | 0.28           | 1.557 | 1,4  | 0.28  |
| H    | 1.48       | 0.40  | 0.08           | 0.453 | 1,5  | 0.531 | 1.57       | 0.15  | 0.02           | 0.118 | 1,5  | 0.745 |
| I    | 1.5        | 2.17  | 0.25           | 1.995 | 1,6  | 0.208 | 1.48       | 1.62  | 0.30           | 2.58  | 1,6  | 0.159 |
| J    | 2.70       | 0.15  | 0.00           | 0.038 | 1,10 | 0.849 | 2.66       | 0.10  | 0.01           | 0.056 | 1,10 | 0.818 |
| K    | 5.22       | 0.28  | 0.12           | 1.826 | 1,13 | 0.2   | 5.24       | 0.23  | 0.12           | 1.703 | 1,13 | 0.215 |
| L    | 3.85       | -0.09 | 0.01           | 0.55  | 1,4  | 0.814 | 3.48       | 0.08  | 0.02           | 0.063 | 1,4  | 0.814 |

**Appendix 3.3** Among-orchard dispersion of adult WFT at several different tree developmental stages. Means given are on a per bud basis.

| Year | Bud stage  | Means<br>Range | Taylor Power law |      |                | Iwao regression |      |                |
|------|------------|----------------|------------------|------|----------------|-----------------|------|----------------|
|      |            |                | a                | b    | r <sup>2</sup> | a               | b    | r <sup>2</sup> |
| 1993 | pink       | 0.02-0.65      | -0.45            | 1.42 | <b>0.92</b>    | -0.91           | 1.37 | <b>0.97</b>    |
| 1993 | bloom      | 0.02-0.21      | -0.93            | 1.06 | <b>0.59</b>    | -0.89           | 1.04 | <b>0.53</b>    |
| 1993 | late bloom | 0.10-0.79      | -1.36            | 0.53 | <b>0.47</b>    | -0.87           | 1.08 | <b>0.96</b>    |
| 1993 | petal fall | 0.02-0.16      | -0.65            | 1.23 | <b>0.84</b>    | -0.87           | 1.36 | <b>0.28</b>    |
| 1993 | larvae     | 0.01-2.38      | -0.54            | 1.49 | <b>0.75</b>    | -1.09           | 1.50 | <b>0.93</b>    |
| 1994 | petal show | 0.08-0.32      | -1.45            | 0.36 | <b>0.13</b>    | -0.79           | 0.58 | <b>0.38</b>    |
| 1994 | pink       | 0.03-0.98      | -0.88            | 1.26 | <b>0.85</b>    | -0.91           | 1.05 | <b>0.97</b>    |
| 1994 | bloom      | 0.03-0.56      | -0.40            | 1.52 | <b>0.66</b>    | -1.10           | 2.50 | <b>0.61</b>    |
| 1994 | late bloom | 0.06-1.00      | -0.99            | 0.83 | <b>0.35</b>    | -0.80           | 0.93 | <b>0.82</b>    |
| 1994 | petal fall | 0.01-0.49      | -0.90            | 1.20 | <b>0.62</b>    | -0.92           | 1.25 | <b>0.70</b>    |
| 1994 | larvae     | 0.06-5.43      | -0.40            | 1.46 | <b>0.90</b>    | -0.53           | 1.08 | <b>0.86</b>    |



**Appendix 3.4** Dispersion of adult WFT from sticky cards for each of orchards A, C and I for several different collection dates. Means given are per side of a single sticky card.

| Orchard | Date | Means<br>Range | Taylor's Power Law |      |                | Iwao's regression |      |                |
|---------|------|----------------|--------------------|------|----------------|-------------------|------|----------------|
|         |      |                | a                  | b    | r <sup>2</sup> | a                 | b    | r <sup>2</sup> |
| A       | 18/4 | 0.63-2.38      | 0.17               | 0.70 | <b>0.35</b>    | 1.15              | 0.54 | <b>0.14</b>    |
| A       | 22/4 | 3.00-14.38     | -1.51              | 2.45 | <b>0.70</b>    | -1.13             | 1.20 | <b>0.93</b>    |
| A       | 26/4 | 0.00-2.00      | -0.05              | 1.28 | <b>0.64</b>    | -0.49             | 1.4  | <b>0.82</b>    |
| A       | 29/4 | 0.00-3.13      | 0.29               | 3.14 | <b>0.85</b>    | -0.35             | 1.49 | <b>0.89</b>    |
| A       | 3/5  | 4.00 -7.00     | -2.86              | 1.89 | <b>0.68</b>    | -8.50             | 2.21 | <b>0.87</b>    |
| C       | 22/4 | 1.00-5.50      | 0.14               | 1.29 | <b>0.82</b>    | 0.22              | 1.24 | <b>0.91</b>    |
| C       | 26/4 | 0.63-2.90      | -0.04              | 1.82 | <b>0.76</b>    | -0.44             | 1.50 | <b>0.75</b>    |
| C       | 1/5  | 0.67-4.88      | 0.25               | 0.78 | <b>0.33</b>    | 0.68              | 1.00 | <b>0.92</b>    |
| C       | 5/5  | 1.25-12.75     | 0.17               | 1.01 | <b>0.66</b>    | 0.91              | 0.95 | <b>0.94</b>    |
| C       | 8/5  | 1.25-6.38      | 0.50               | 0.59 | <b>0.22</b>    | 1.48              | 0.90 | <b>0.91</b>    |
| C       | 14/5 | 15.63-39.38    | 0.44               | 1.30 | <b>0.38</b>    | 5.38              | 1.07 | <b>0.92</b>    |
| I       | 23/4 | 0.63-1.90      | -0.01              | 0.12 | <b>0.00</b>    | 0.51              | 0.99 | <b>0.15</b>    |
| I       | 27/4 | 0.50-1.88      | -0.42              | 2.10 | <b>0.59</b>    | -1.09             | 1.62 | <b>0.75</b>    |
| I       | 1/5  | 0.57-1.75      | 0.12               | 1.88 | <b>0.83</b>    | -1.15             | 2.62 | <b>0.77</b>    |
| I       | 5/5  | 0.63-4.13      | -0.18              | 1.64 | <b>0.86</b>    | -0.65             | 1.35 | <b>0.98</b>    |

**Appendix 3.5a** Regression statistics for Iwao's Regression/Taylor's Power Law (see Appendix 4) for catches of adult WFT on sticky cards in orchards A, C and I.

| <b>Orchard</b> | <b>Date</b> | <b>F</b> | <b>df</b> | <b>P</b>     |
|----------------|-------------|----------|-----------|--------------|
| A              | 18/4        | 0.991    | 1,6       | 0.358        |
| A              | 22/4        | 76.621   | 1,6       | <b>0.000</b> |
| A              | 26/4        | 12.066   | 1,4       | <b>0.026</b> |
| A              | 29/4        | 25.938   | 1,4       | <b>0.007</b> |
| A              | 3/5         | 41.598   | 1,6       | <b>0.001</b> |
| C              | 22/4        | 61.459   | 1,6       | <b>0.000</b> |
| C              | 26/4        | 18.156   | 1,6       | <b>0.005</b> |
| C              | 1/5         | 67.186   | 1,6       | <b>0.000</b> |
| C              | 5/5         | 79.02    | 1,5       | <b>0.000</b> |
| C              | 8/5         | 57.781   | 1,6       | <b>0.000</b> |
| C              | 14/5        | 69.59    | 1,6       | <b>0.000</b> |
| I              | 23/4        | 1.036    | 1,6       | 0.348        |
| I              | 27/4        | 18.234   | 1,6       | <b>0.005</b> |
| I              | 1/5         | 28.623   | 1,6       | <b>0.002</b> |
| I              | 5/5         | 299.894  | 1,6       | <b>0.000</b> |

**Appendix 3.5b** Statistics for the comparison of the slopes of the above regressions (Appendix 3.5a) with a slope of 1.

| <b>Orchard</b> | <b>Date</b> | <b>Range of means</b> | <b>F</b> | <b>df</b> | <b>P</b>     |
|----------------|-------------|-----------------------|----------|-----------|--------------|
| <b>A</b>       | 22/4        | 3.00-14.38            | 2.084    | 1,6       | <b>0.199</b> |
| <b>A</b>       | 26/4        | 0.00-2.00             | 0.650    | 1,4       | <b>0.465</b> |
| <b>A</b>       | 29/4        | 0.00-3.13             | 3.215    | 1,4       | <b>0.147</b> |
| <b>A</b>       | 3/5         | 4.00 -7.00            | 12.434   | 1,6       | <b>0.012</b> |
| <b>C</b>       | 22/4        | 1.00-5.50             | 2.352    | 1,6       | <b>0.176</b> |
| <b>C</b>       | 26/4        | 0.63-2.90             | 1.99     | 1,6       | <b>0.208</b> |
| <b>C</b>       | 1/5         | 0.67-4.88             | 0.001    | 1,6       | <b>0.980</b> |
| <b>C</b>       | 5/5         | 1.25-12.75            | 0.195    | 1,5       | <b>0.677</b> |
| <b>C</b>       | 8/5         | 1.25-6.38             | 0.678    | 1,6       | <b>0.442</b> |
| <b>C</b>       | 14/5        | 15.63-39.38           | 0.261    | 1,6       | <b>0.628</b> |
| <b>I</b>       | 27/4        | 0.50-1.88             | 2.643    | 1,6       | <b>0.155</b> |
| <b>I</b>       | 1/5         | 0.57-1.75             | 60.232   | 1,6       | <b>0.047</b> |
| <b>I</b>       | 5/5         | 0.63-4.13             | 19.727   | 1,6       | <b>0.004</b> |

## CHAPTER 4

### SPATIAL AND TEMPORAL DISTRIBUTION PART I

#### Spatial and temporal patterns of dispersal of Western Flower Thrips

**ABSTRACT** Western flower thrips, *Frankliniella occidentalis* (Pergande), were sampled from six nectarine orchards in the Dry Central Interior, British Columbia, Canada, between April and June 1993 using yellow sticky cards placed on 2 m-high posts spaced at 30° intervals around the perimeter of each orchard. Abundances of western flower thrips (WFT) and the other commonly captured species of thrips, and direction of their movement into and out of the orchards were monitored in relation to the following factors: wind direction; temperature; vegetation surrounding and within orchards; and the stage of development of the nectarine buds. Vertical variation in WFT movement was assessed using cards placed at heights of 0.25, 1, 1.5 and 2 m and correlated with the type of ground cover in each orchard. A comparison of thrips abundance and flight patterns was made between orchards located in two differently oriented valleys (N-S and E-W) and between orchards located close to or far from areas of wild land. Sticky cards also were set up within orchards (on posts between trees) and within areas of wild land. The cards provided information on patterns of flight within orchards and areas of wild land and density changes of different species of thrips over the season. WFT were the species most commonly caught on sticky cards. No obvious differences in species composition were seen among the orchards located in the northern and southern parts of the Dry Central Interior. Densities of thrips entering orchards, and their direction of movement, was more related to the external vegetation than either location within the two different valleys on the large scale or general wind flow patterns. In general, thrips moved into and out of orchards close to ground level in spring and moved higher as both vegetation grew higher and temperatures increased.

**KEY WORDS** *Frankliniella occidentalis*, nectarine, flight patterns, dispersal, circular statistics, western flower thrips

#### 4.1 INTRODUCTION

Western flower thrips, *Frankliniella occidentalis* (Pergande) (WFT), are serious pests in nectarine orchards in the Dry Central Interior, British Columbia, Canada. Adult female thrips lay their eggs in the developing nectarine buds early in spring; these develop and hatch into larvae approximately at the stage of petal fall. Although adult WFT are

believed to cause damage to nectarines in other areas (e.g. Pennsylvania and Georgia in the U.S., France) (Yonce *et al.*, 1991a; Felland *et al.*, 1993b; Grasselly *et al.*, 1993), it is the larvae that damage nectarines in this region: larval feeding on the developing fruitlets causes minute scars which result in large patches of superficial rusting on the mature fruit. In serious cases, the rusting cracks and exudes gum, which causes the fruit to be attractive to other pests such as earwigs. Damaged fruit is either downgraded or culled.

It has been suggested that strong regional, temporal and varietal differences in the damage to fruit exist in this region (E. Hogue, pers.comm.). This study was carried out to assess spatial and temporal patterns of thrips flight into and out of orchards, and to determine whether the location of an orchard --both within the Dry Central Interior (north or south) and relative to its proximity to wild land -- has any effect on the densities and species of thrips captured. It is generally assumed that the areas of wild land surrounding orchards comprise the prevalent overwintering grounds for these insects, and I thus assumed that orchards bordering such regions might possess the highest densities and diversity of thrips. An assessment of nectarine variety effects is made elsewhere (Pearsall, chapter 3).

Studies of flight and dispersal of WFT have been conducted primarily in greenhouses (e.g. Gillespie and Vernon, 1990; Vernon and Gillespie, 1995), although there have been several studies of the movement of thrips in the field situations, for example, flight into and around cabbage fields (Shelton and North, 1986), peanut fields (Barbour and Brandenburg, 1994), tomato fields (Puche *et al.*, 1993, 1995) and in ripe stonefruit in New Zealand (Teulon and Penman, 1996). Comprehension of the movement patterns of WFT into, out of and within a particular crop is necessary to provide information for possible management strategies. I tried to determine whether thrips move into orchards in the early spring as the trees come into bloom, or whether they are already present within the orchards. Knowledge of the occurrence of peak movement into orchards might enable growers to optimally time pest management strategies. Western flower thrips

are minute insects and both sexes are capable of flight. However, it is the movement patterns of the adult females which are of most interest with regard to pest management, as damage levels are a direct consequence of oviposition by the female.

Studies of the flight behaviour of orchard pests have employed sticky cards, light traps, and pheromone baited traps as well as a whole suite of other types of traps (Prokopy and Owens, 1978, 1983). In the case of western flower thrips, coloured sticky traps and water pan traps have been the preferred choices. Sticky traps have been used for monitoring, forecasting, and with limited success, for mass trapping of thrips (Higgins and Myers, 1992; Puche *et al.*, 1995; Kawai and Kitamura, 1987). There have been numerous studies on the most effective shape, size (e.g. Vernon and Gillespie, 1995), positioning (e.g. Lewis, 1959; Yudin *et al.*, 1987; Gillespie and Vernon, 1990; Coli *et al.*, 1992; Vernon and Gillespie, 1995) and colour (Lewis, 1959; Kirk, 1984a,b; Brodsgaard, 1989b; Gillespie and Vernon, 1990; Teulon and Penman, 1992; Vernon and Gillespie, 1995) of sticky traps that may be used in these different situations. Results of these studies suggest that blue, yellow and non-UV-reflecting white traps may be the most effective colours. I decided to use yellow sticky cards because the WFT are highly contrasted and therefore easily counted against a yellow background and because yellow cards were the most readily available commercially. Although I was primarily interested in movement patterns of WFT, the sticky cards also trapped other species of thrips and thus provided information on the spatial and temporal distribution of several species.

Finally, I wished to examine how height of movement by thrips changes over the season, as nectarine development occurs and the climate and vegetation within orchards change. In particular, I wanted to determine whether thrips are more common at the level of the ground cover within orchards or at tree canopy level, and how this varies over the period of bud development. Such an understanding of the height at which thrips fly could prove invaluable for the use of trap crops, or the construction of barriers at the orchard edge.

I used a circular design of sampling units to study direction of movement (Batschelet, 1981). Sticky cards were thus placed on twelve posts at the orchard edge and located approximately every 30° from the centre of the orchard. By placing sticky cards both facing into and out of the orchard, I could compare the flight to and from the orchards. Similarly, by placing cards at various heights up the length of the posts, I was able to examine height effects. Sticky cards were also placed on posts situated within orchards to examine patterns of flight among the trees.

Finally, because I was interested in determining the source areas for these thrips, I also examined the flight of thrips within two patches of wild land (predominantly sagebrush, *Artemisia tridentata* Nutt.) bordering two of the orchards. I wished to determine when flight activity was taking place in these areas, whether it was synchronous among the two areas, and whether the peaks of thrips movement were coincident with those in the orchards.

## 4.2 MATERIALS AND METHODS

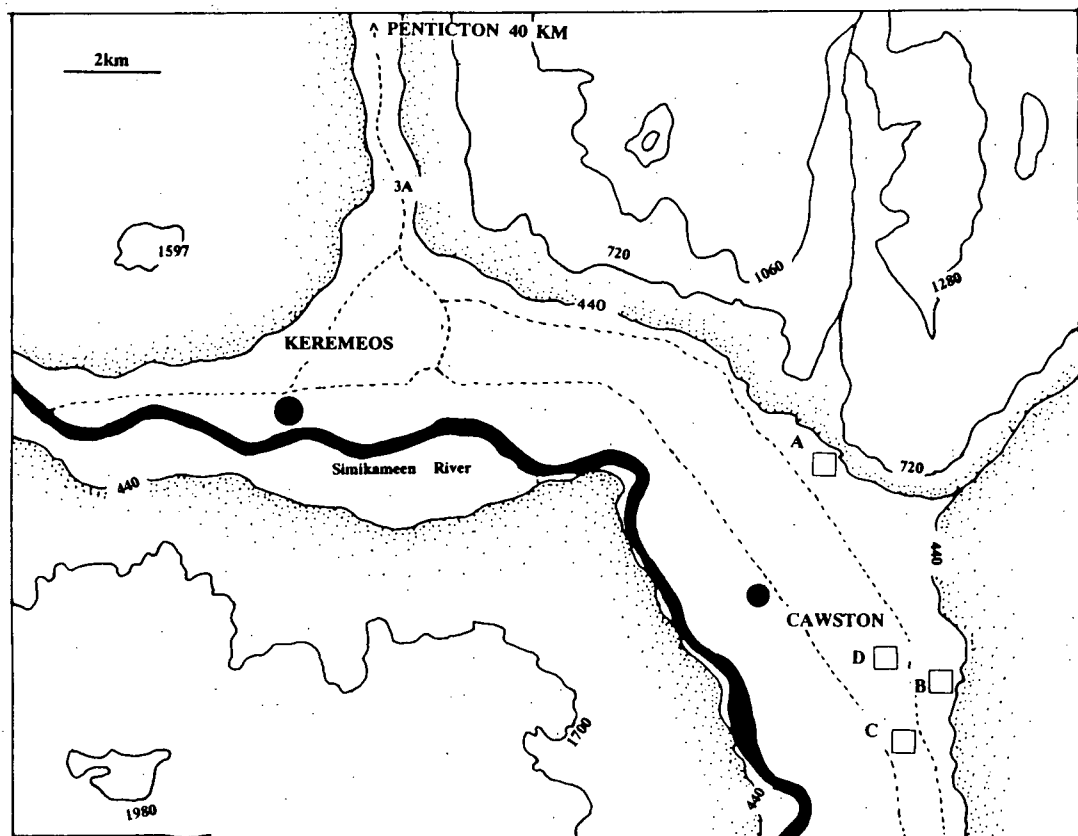
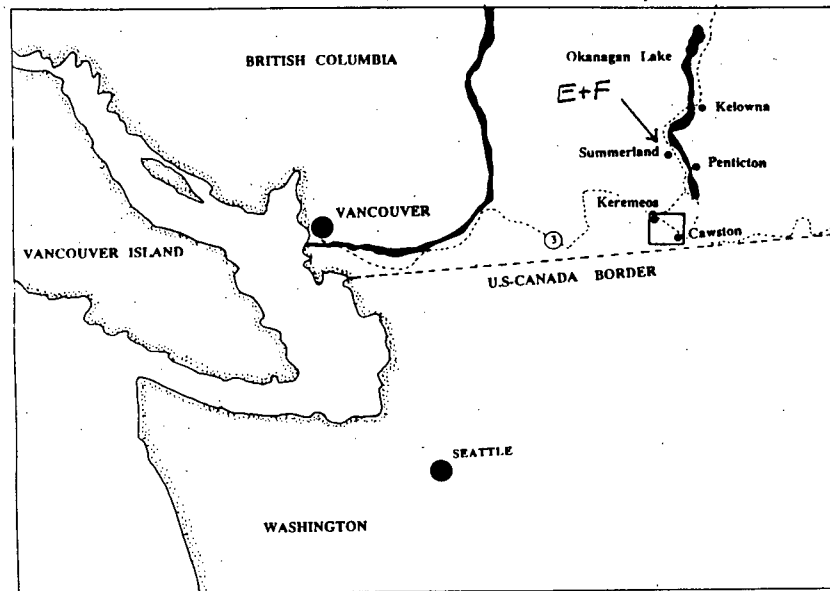
### Study sites

The dispersal studies were carried out in six nectarine orchards in British Columbia (four in Cawston (A, B, C, D) and two in Summerland (E, F)), between April and June (Figure 4.1). The orchards chosen for this study differed with respect to location and the type of surrounding vegetation. Orchards A, B, C and D are in the southern Similkameen valley which runs approximately northwest to southeast. Orchards E and F are located next to the Okanagan Lake in the Okanagan Valley which runs northeast to southwest. These two orchards are highly exposed and lie adjacent to patches of wild land. Orchards A and B are both located on the hillside and are flanked on one side by large areas of wild land. Orchards C and D are both in the valley bottom. Only orchard D does not lie adjacent to any areas of wild land, but is surrounded by other orchards.

### Sticky traps

To monitor dispersal, thrips were sampled using yellow sticky cards (7.5 cm by 13 cm) (Phero Tech Inc., 7572 Progress Way, Ladner, British Columbia) placed on two-metre-high posts spaced at 30° intervals around the perimeter of each orchard (Figures 4.2a-f). On each "peripheral orchard" post, cards were paired so that 3-4 faced in towards the orchard (IN cards), and the other 3-4 faced outwards (OUT cards). These cards were put out in early April while the buds were still dormant (5 and 13 April for the southern and northern orchards, respectively), and were collected every three to four days (or as necessary based on numbers of thrips) until 31 May/1 June. Densities of thrips and direction of their movement into and out of the orchards were monitored in relation to wind direction, surrounding vegetation, temperature, and the stage of development of the nectarine buds. Vertical variation in movement of thrips was assessed using cards placed at heights of 0.25 (ground), 1 (low), 1.5 (medium) and 2 m (high) and correlated with tree





**Figure 4.1a,b** Location of a) orchards A-F in the Dry Central Interior, British Columbia.

height and the type of ground cover in each orchard. Sticky cards were also collected from a fifth height (2.5 metres- labelled 'Top' for two collections dates (8 and 15 May)) in orchard C only. The ground level cards were put into all orchards except F, on 1 May, when dandelions (*Taraxum officinale* Weber) were in full bloom. Numbers of WFT were so high per card in mid-May that, to make the amount of time spent counting reasonable, between 23-25 May, only the medium and low level cards were placed onto posts. Thus, WFT were counted from a total of only 4 cards per post for the 31 May/1 June collection.

Sticky cards were also placed among weeds in areas of uncultivated land around orchards A and B (Figures 4.2a,b). Eight one-metre-high posts were put out with two sticky cards attached at the average level of the surrounding wild vegetation, and these were sampled at the same time as the sticky cards surrounding the orchards. One of the pair of sticky cards faced in towards the orchard, and the other of the pair faced outwards.

Sticky traps also were used in five of the orchards (B, C, D, E and F) to trap thrips flying within the orchard (Figures 4.2b-f). Four to six posts were set up within each orchard (depending on orchard size) and two cards were attached at the height of tree mid-canopy (H) for all dates between 18 April and 1 June, and for all orchards except F, at 25 cm from ground level (G) after 4 May, by which time dandelions had bloomed. The posts were placed randomly between trees and the cards were removed at the same time as the cards on the outside posts. For these "Interior" posts, the direction in which the cards faced was random, and could not be associated with an 'out ' or 'in' direction. Changes in abundance of thrips on sticky traps placed between trees were used as an indication of changes in the activity of these insects.

### **Nectarine development**

The development of buds on each of eight randomly chosen sample trees within each orchard was scored into the following categories: "silver tip", "swelling bud", "petal show", "full pink", "bloom", and "petal fall". The first category represents all the nectarine

Figure 4.2a

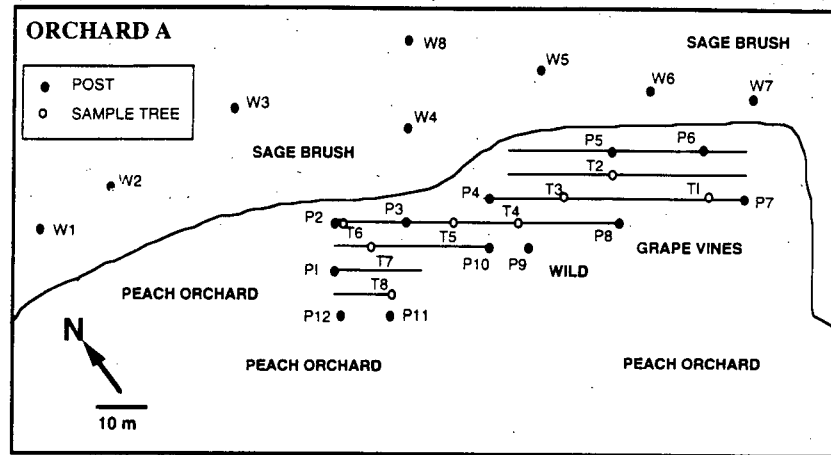


Figure 4.2b

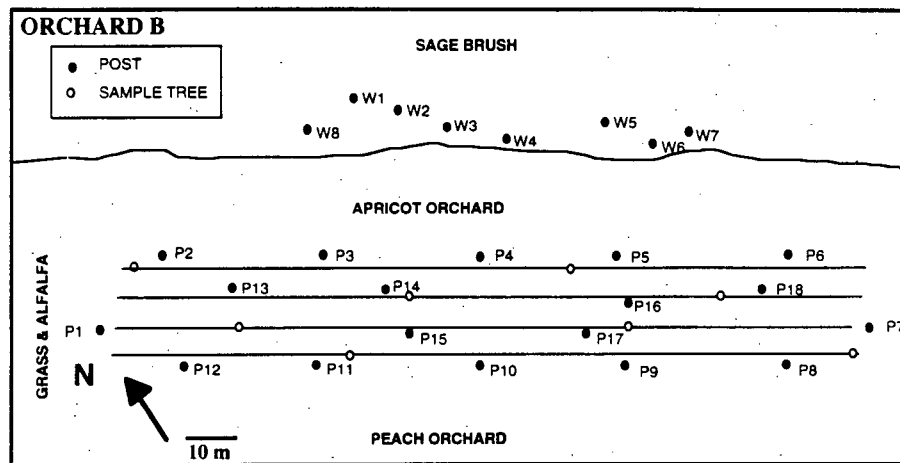
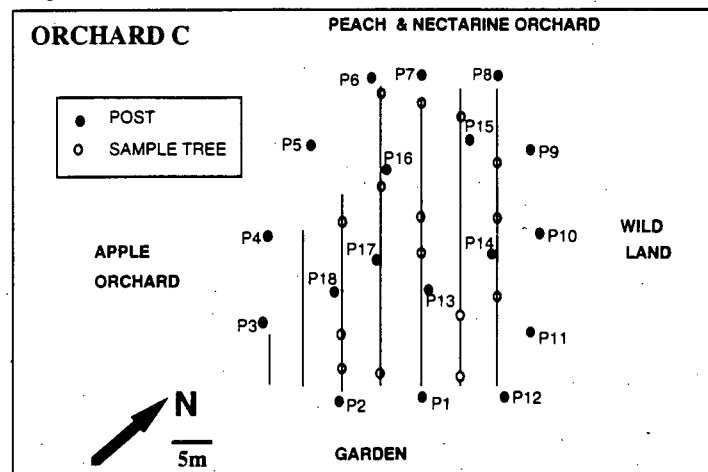


Figure 4.2c



**Figure 4.2a-c** Maps of orchards A-C showing the orchard size, location of peripheral posts, interior posts (for orchards B,C) and wild land posts (for wild land adjacent to orchards A and B) as well as orchard orientation and surrounding vegetation.

Figure 4.2d

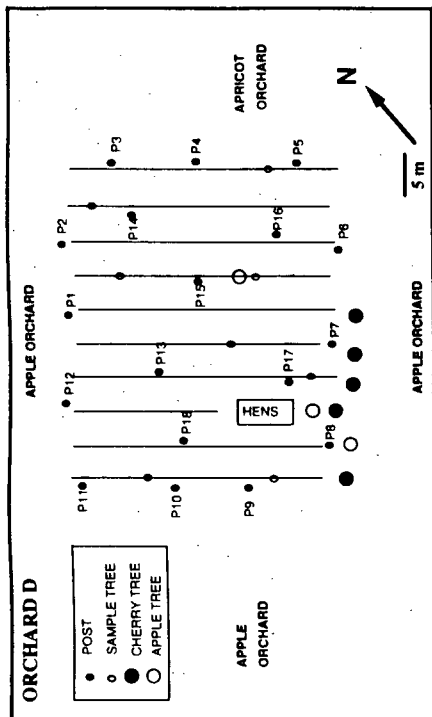


Figure 4.2f

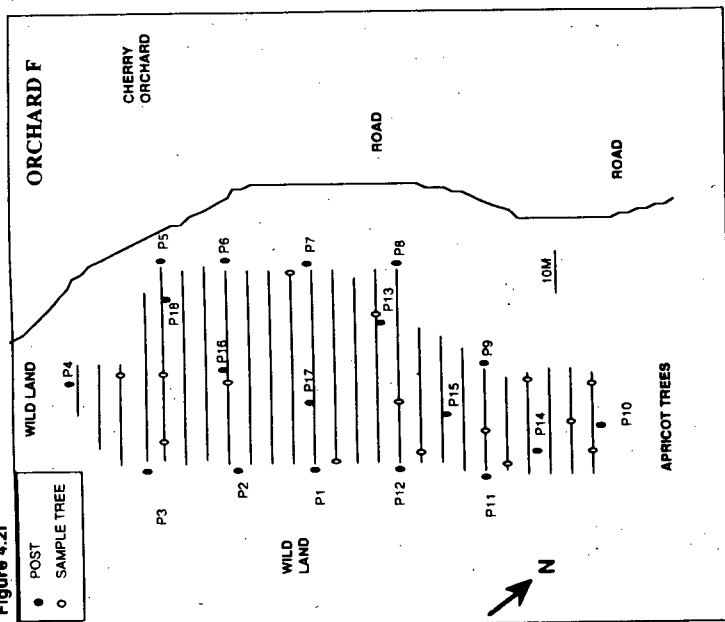


Figure 4.2e

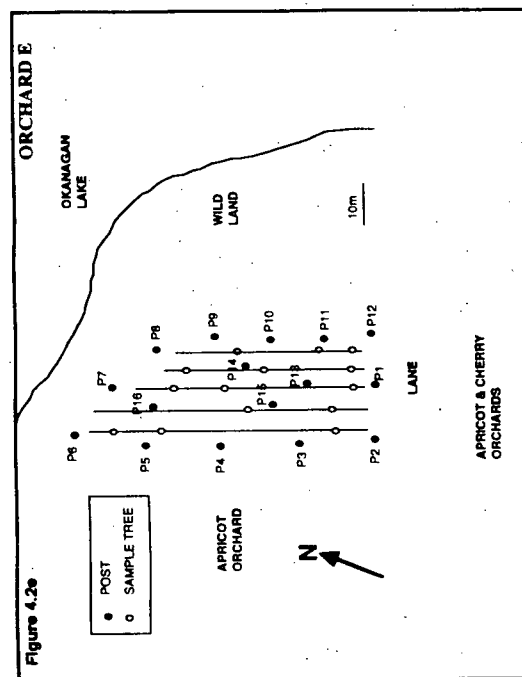


Figure 4.2d-f Maps of orchards D-F showing the orchard size, location of peripheral posts, and interior posts as well as orchard orientation and surrounding vegetation.

buds that are still dormant which appear tight and silver coloured. The second category includes the buds that are coming out of dormancy and beginning to swell: these buds appear rounder and whiter than dormant buds. The third category of buds include all those in which a small amount of pink coloured petal may be seen, signifying that the bud has clearly begun to open. Full pink is the "popcorn" stage. The bloom stage includes all flowers where the petals have opened, including buds where the petals have begun to deteriorate. Petal fall includes all buds from which petals have begun to fall (Figure 4.3)

### **Insect identification**

Sticky cards were soaked in varsol overnight or until the Stickum® glue had dissolved. Thrips floating in varsol were removed using a camel hair brush and placed into vials of ethanol. When time permitted, these thrips were mounted in a drop of Hoyer's solution on glass slides. After at least two weeks of curing, or drying, these slides were sent to Dr. Steve Nakahara at U.S.D.A., Maryland, for identification. This was a laborious process: because of the Stickum®, thrips often lost antennae or part of wing/legs/setae during the extraction process, and thus were not adequate for identification purposes. The most commonly occurring thrips were mounted and identified, but for some of the more uncommon species it was not possible to successfully mount any individuals.

### **Weather Records**

Temperature and precipitation data recorded directly in Keremeos were provided by Environment Canada.

The two Summerland orchards are located within 5 km of the Summerland Agriculture and Agri-Food Canada Research Centre, and thus the weather records produced at the station were assumed to adequately represent the weather conditions in these orchards.

**Dormant Bud**



**White Swell (WS)**



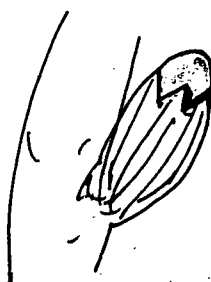
**Pink Colour (PC)**



**Petal Show (PS)**



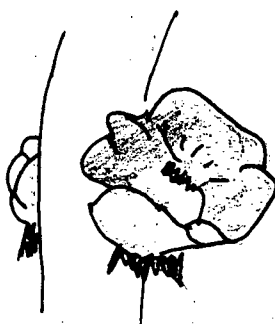
**Early Pink**



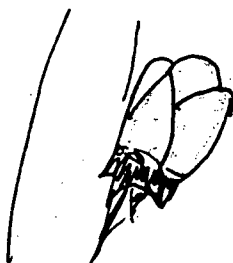
**Full Pink**



**Full Bloom**



**Early Bloom**



**Petal Fall**



**Figure 4.3** Diagram of nectarine buds at various stages through development, namely, silver tip, swelling bud, pink colour, petal show, full pink, bloom and petal fall.

## Data Analysis

Abundance of WFT in flight within orchards was described using the mean number of WFT per sticky card expressed on a per day basis, so that catches after differing periods of time could be compared. These adjusted densities of thrips caught on each date were compared between orchards using ANOVA ( $P < 0.05$  significance level). Where data did not meet the assumptions of ANOVA, and where numbers could not be adequately transformed, a non-parametric Kruskal-Wallis test was used. Tukey's HSD test was used for all post-hoc comparisons of ANOVA results. A Mann-Whitney U test was used for post-hoc comparisons of Kruskal-Wallis results with a Bonferroni adjustment to control the experiment wise probability of a type I error to 5%.

Mean direction of thrips movement into and out of orchards was assessed for each date using circular statistics (Rayleigh's test,  $P < 0.05$  significance level). The mean angle of flight of thrips into orchards was determined as  $\bar{\theta}$  for each date for each orchard and Rayleigh's test was used to determine whether the direction of flight departed significantly from random (Batschelet, 1981). Rayleigh's test has the advantage that the calculation also yields measures of dispersion ( $s$ ) and concentration ( $r$ ) where,  $s = 1 - r$ .

For those dates when densities were particularly low, and there were no significant orientation effects (see below), I pooled the number of thrips on the "out" and "in" facing cards and performed Rayleigh's test on the pooled densities. However, for all other dates, the circular statistics were carried out on both the "out"- and "in"-facing cards separately, as well as the on pooled densities.

Height (ground, low, medium and high) and orientation (in, out) of thrips movement into and out of orchards was analysed by two-way ANOVA for each date using unadjusted data ( $P < 0.05$  significance level).

### 4.3 RESULTS

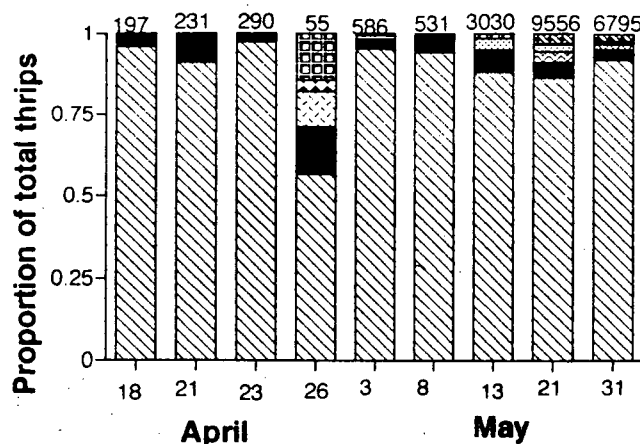
#### Species

The most commonly captured species of thrips flying into orchards during the period of nectarine flower development were: *F. occidentalis* (Pergande) (WFT pale and dark forms), a newly described species *Thrips fallaciosus* Nakahara, and *Haplothrips kurdjumovi* Karny . The other most commonly captured thrips species were: *T. treherni* Priesner, *F. minuta* (Moulton), *T. tabaci* Lindeman, *Aeolothrips fasciatus* (Linnaeus), *T. vulgatissimus* Haliday, *H. verbasci* (Osborn), *H. halophilus* Hood, *Neohydatothrips* sp. and various *Aeolothrips* spp. Of these species, only the *Haplothrips* spp. and the *Aeolothrips* spp. are predacious. The other species are phytophagous and belong to the family Thripidae. The *Haplothrips* spp. belong in the family Phlaeothripidae. *Frankliniella fusca* (Hinds) and *Odontothrips loti* (Haliday) were also identified from specimens, but were more rarely caught and not enumerated from each sticky card. Some of the least commonly captured species were not identified due to the difficulty of extraction from sticky cards.

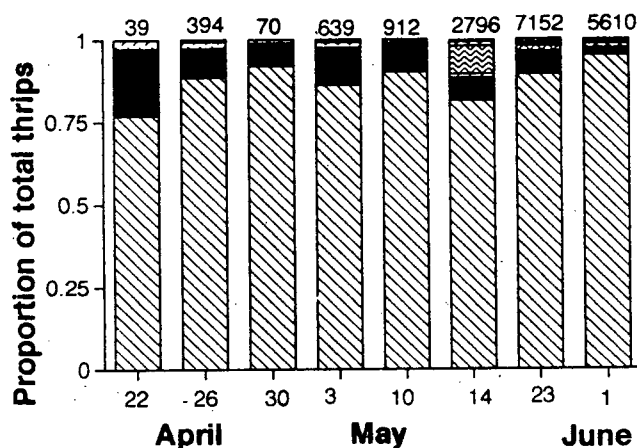
For all dates, WFT was the most abundant species present in all orchards, irrespective of location. The proportion of WFT on sticky cards located at the orchard periphery for all dates was greater than 71% for orchard A, 93% for orchard B, 92% for orchard C, 77% for orchard D, 74% for E and 87% in orchard F (Figures 4.4a-f). The dark and pale forms of WFT, *H. kurdjumovi* and *T. fallaciosus* were the main species that were captured on sticky cards during April. There was an increased diversity of thrips species caught beginning in early May, with initial catches of *Aeolothrips* sp., *H. halophilus*, *T. treherni* and *T. tabaci* . By the end of May, the numbers of species caught increased further, and there were in addition to the above species, catches of *H. verbasci*, *T. vulgatissimus*, *Neohydatothrips* sp., and *F. minuta*, as well as a variety of other species that remain unidentified. *Haplothrips verbasci* was found only in the northern orchards.



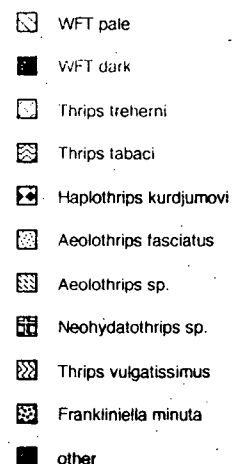
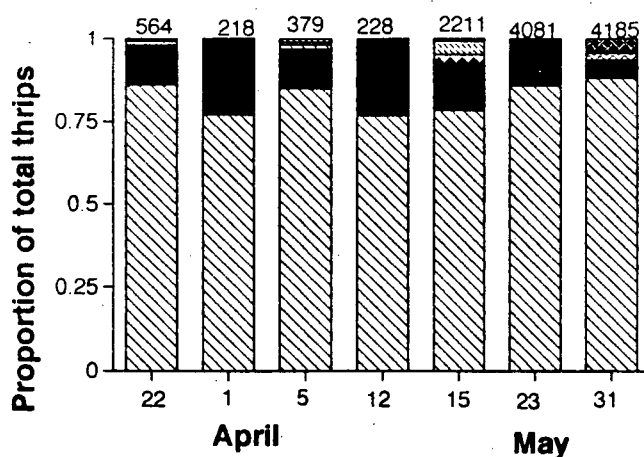
**Figure 4.4a Orchard A outside posts**



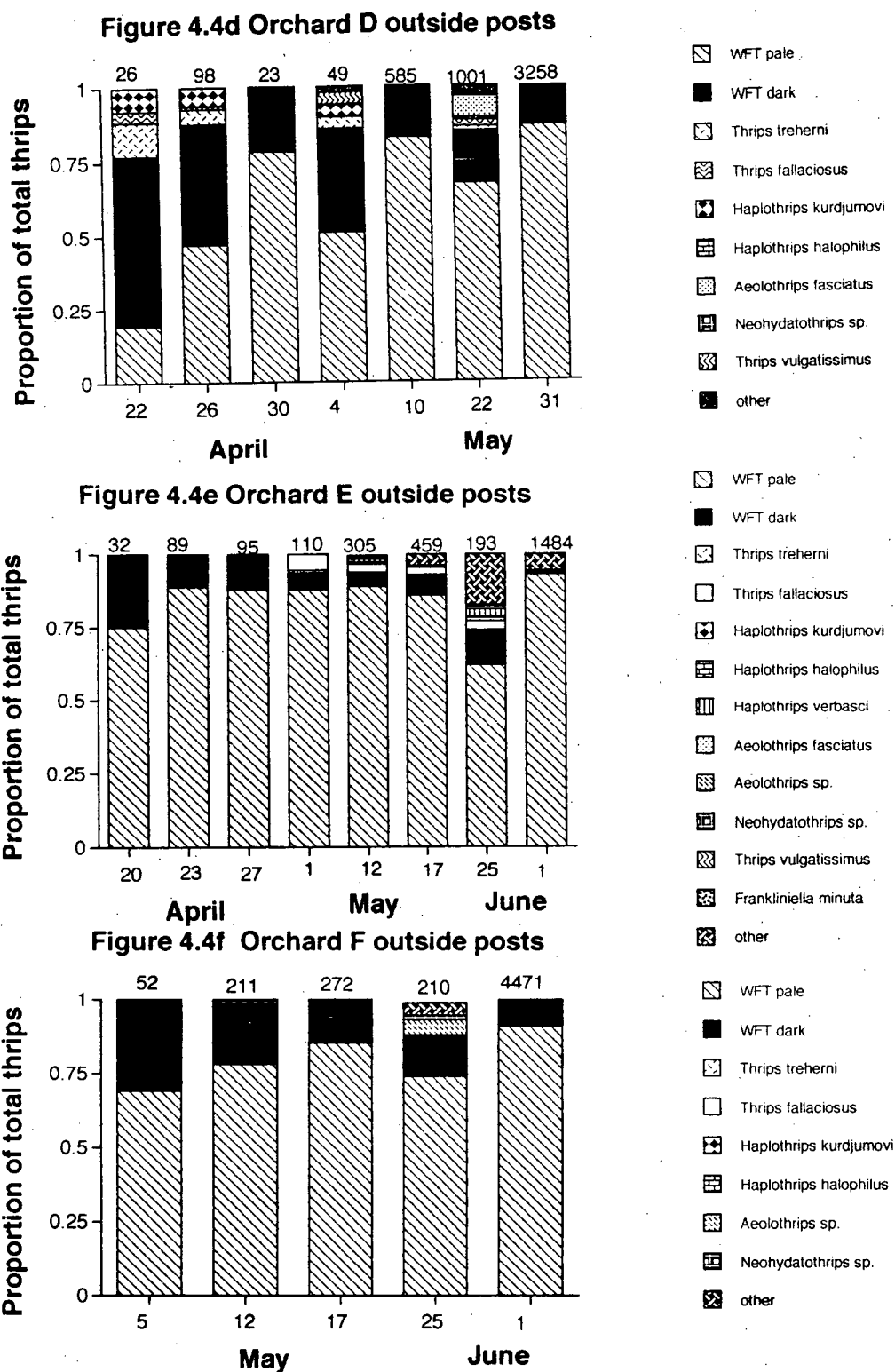
**Figure 4.4b Orchard B outside posts**



**Figure 4.4c Orchard C outside posts**



**Figure 4.4a-c** The species composition of thrips as caught on sticky cards located on peripheral posts around orchards A-C from 18 April - 1 June 1993.



**Figure 4.4d-f** The species composition of thrips as caught on sticky cards located on peripheral posts around orchards D-F from 18 April - 1 June 1993.

The predacious *Aeolothrips* sp. were seen to increase in all orchards in mid-May. *Thrips treherni* also became common in May, particularly in those orchards with a dense ground cover of dandelion (A and B), in which it is apparently commonly found (Steve Nakahara, pers. comm). Species caught in the northern and southern orchards appeared to be very similar (Figures 4.4a-f).

Although WFT were not separated by sex for this study, I found that only female WFT were present in the early spring, with males only occurring after the emergence of the first generation in mid-May. The emergence of males together with females in the first generation is to be expected if first generation females were mated prior to overwintering. WFT were categorized into the dark and pale morphs for this study. The pale morph was far more common than the dark morph in all orchards studied (Figures 4.4a-f), but a greater ratio of dark: pale morph WFT occurred in orchard D than in the other orchards.

Species of thrips orchard interiors and in wild land were similar to those found on the cards placed at the edges of orchards (Figures 4.5a-g). However, the proportion of dark WFT appeared to be lower on traps in wild areas adjacent to orchards A and B than on the peripheral traps of those same orchards.

#### **Patterns of flight over the season indicated by peripheral traps around orchards.**

Peaks in abundance of thrips were seen at the pink and bloom stages in the southern orchards, particularly in orchards A and B, but such peaks were not readily apparent in the northern orchards. In all six orchards, densities of thrips flying into orchards increased after petal fall, when the first generation emerged from the ground (Figures 4.7a,b). This emergence was also coincident with increased temperatures and reduced precipitation in both areas (Figures 4.6a,b & 4.7a,b).

Figure 4.5a Orchard A wild posts

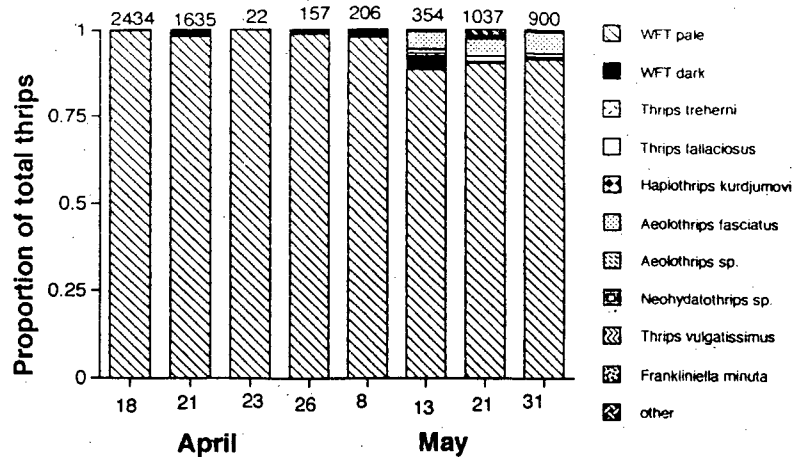


Figure 4.5b Orchard B wild posts

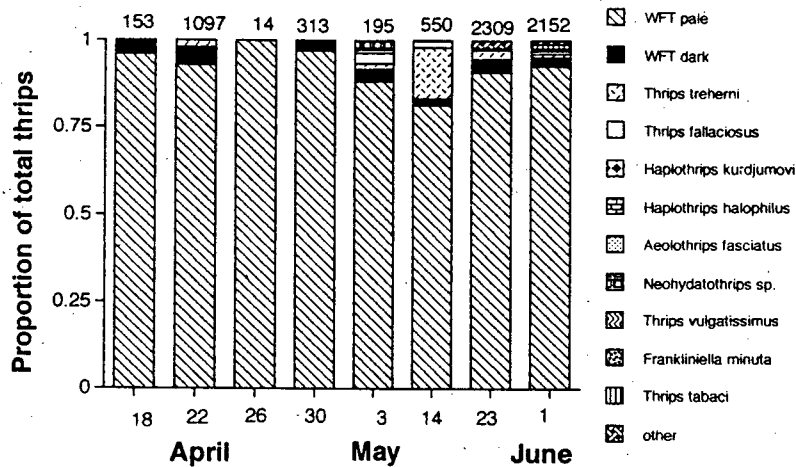


Figure 4.5c Orchard B interior posts

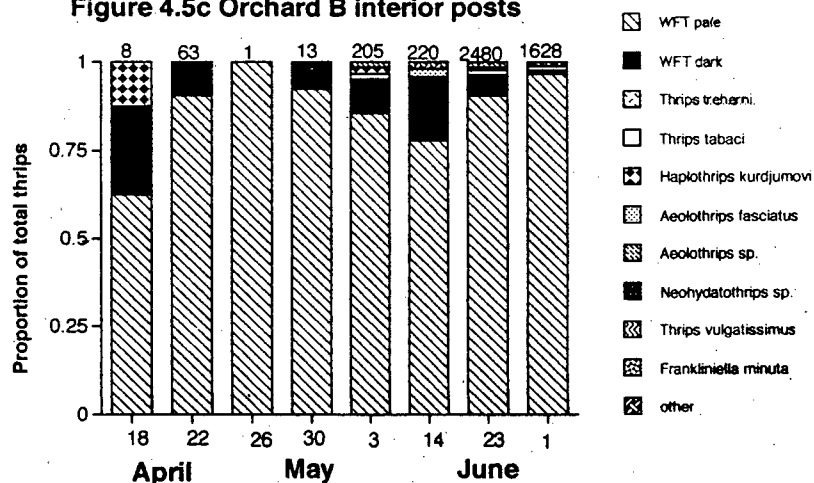
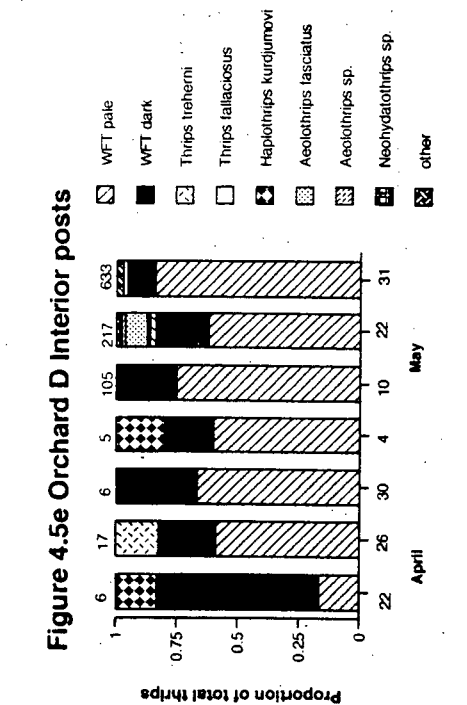


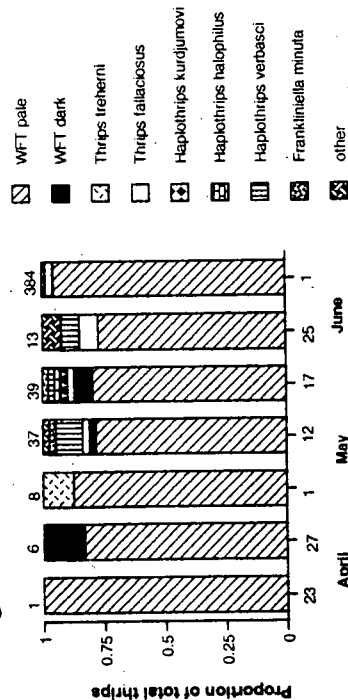
Figure 4.5a-c The species composition of thrips as caught on sticky cards located on a) wild posts adjacent to orchard A, b) wild posts adjacent to orchard B and c) interior posts in orchard B from 18 April - 1 June 1993.



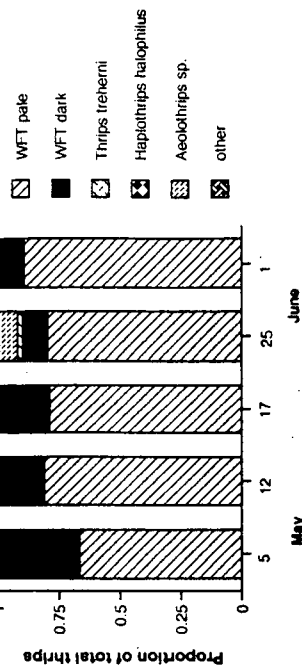
**Figure 4.5e Orchard D Interior posts**



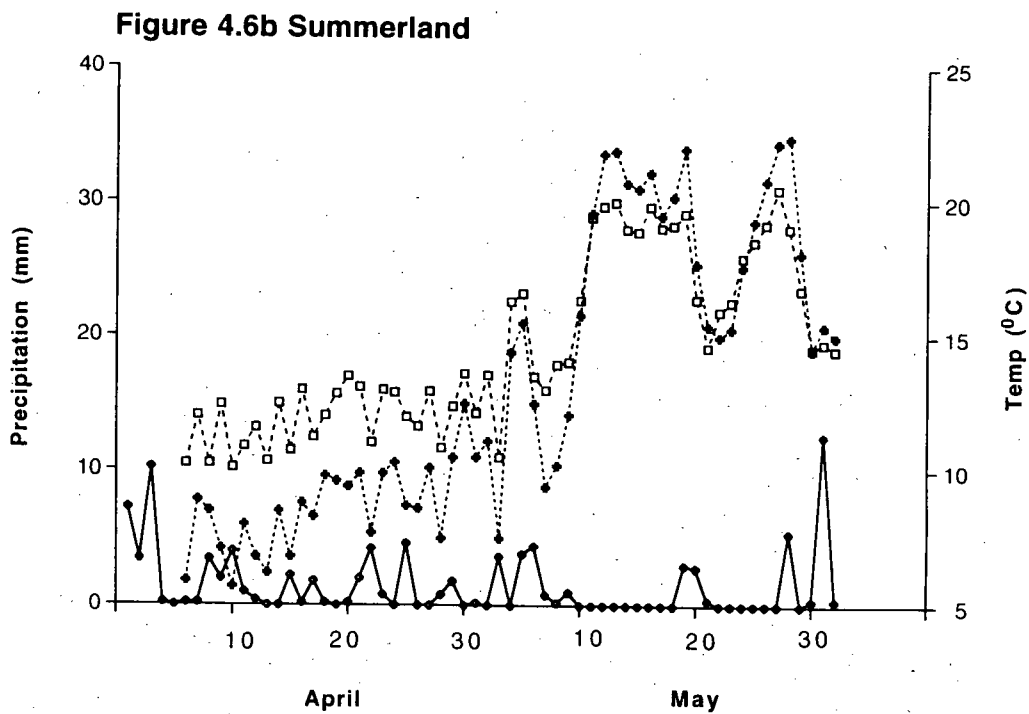
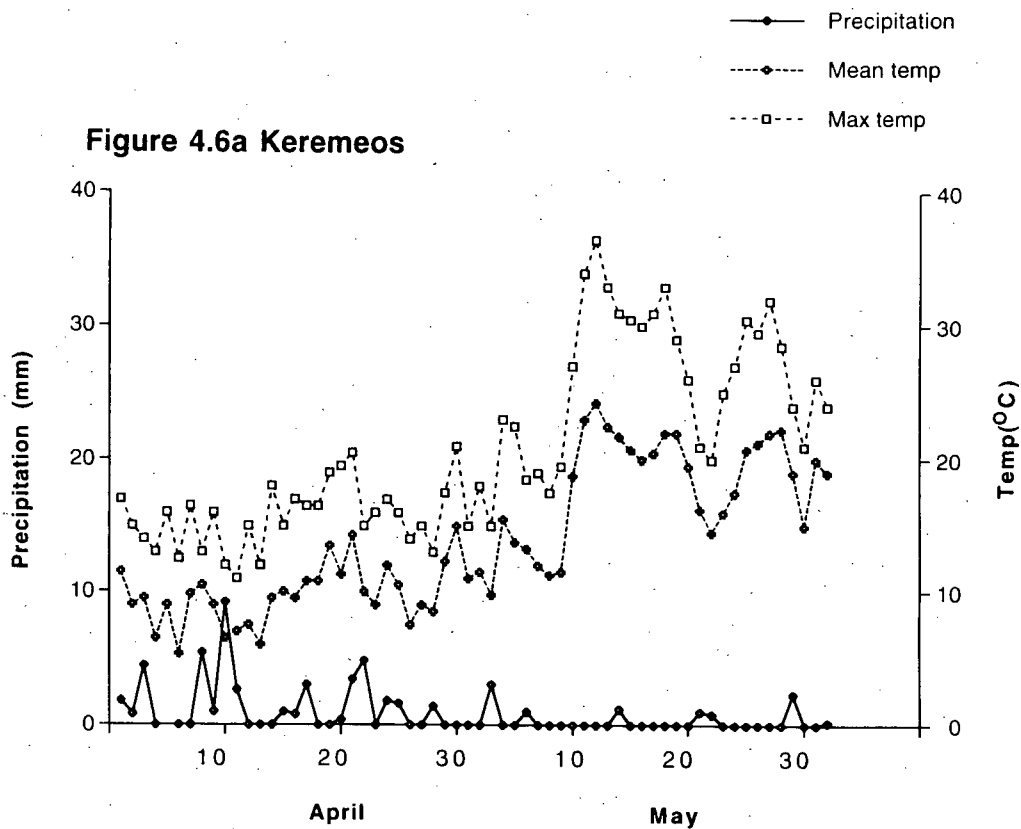
**Figure 4.5f Orchard E Interior posts**



**Figure 4.5g Orchard F Interior posts**

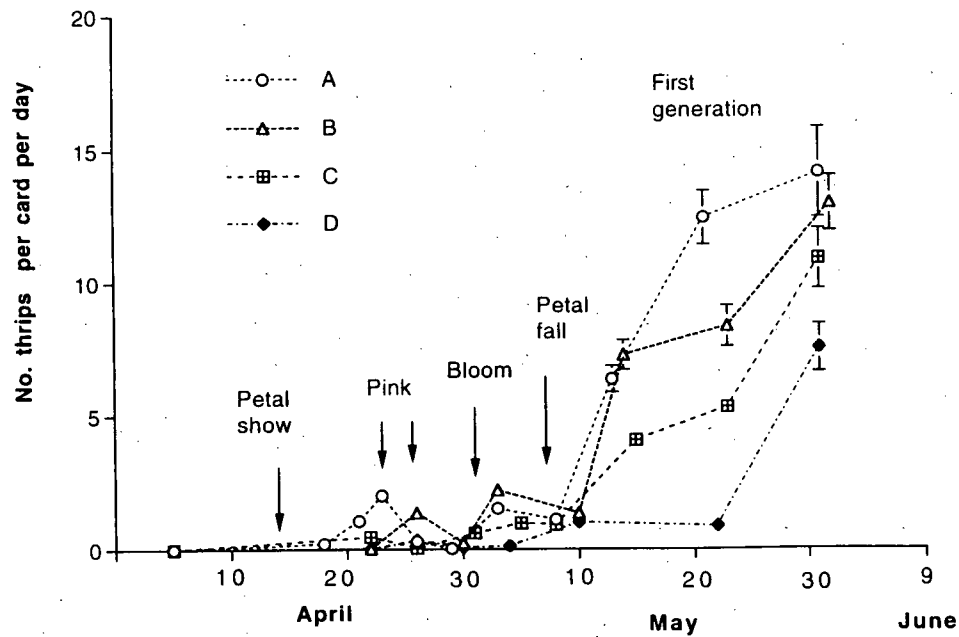


**Figure 4.5d-g** The species composition of thrips as caught on sticky cards located on interior posts within orchards C-F from 18 April - 1 June 1993.

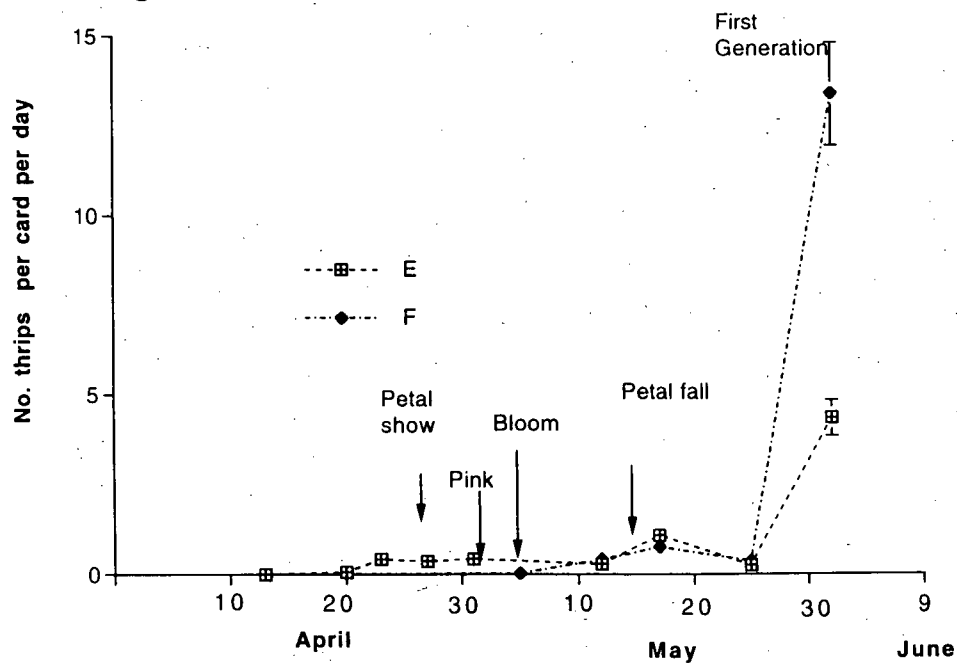


**Figure 4.6a,b** Mean and maximum air temperatures (°C) and precipitation (mm) in a) Keremeos and b) Summerland from 1 April -1 June 1993.

**Figure 4.7a**



**Figure 4.7b**



**Figure 4.7a,b** Mean densities of adult thrips caught per card per day from peripheral posts located around a) orchards A-D and b) orchards E&F from 5 April-1 June 1993.

Comparisons of total numbers of WFT per post over the whole sampling period in southern orchards showed that orchards on the hillside (A and B) had higher densities than orchard C, with the lowest densities overall occurring in orchard D, located far from any wild land ( $F=20.23$ ,  $df=3,43$ ,  $P=0.000$ ). For the northern orchards, higher densities were found in orchard F than in orchard E ( $T=3.74$ ,  $df=22$ ,  $P=0.001$ ). Overall, there were significant differences among the six orchards in terms of the total numbers of WFT caught per post for all dates ( $F=41.27$ ,  $df=5,64$ ,  $P=0.000$ ), with the highest numbers in orchards A and B, followed by C, then F and D, and finally orchard E. A direct comparison of total WFT trapped over the whole study period in southern versus northern orchards, showed that densities were higher in the southern orchards ( $T=6.24$ ,  $df=70$ ,  $P=0.000$ ). I also compared the number of WFT caught per post among orchards for each date separately (Table 4.1). For these analyses, I standardized counts so that they were expressed over the same period of days since sticky cards were collected after variable periods of time in the different orchards. In general, higher densities of thrips were found on each date in the orchards located on a hillside, namely A and B, with lower densities caught in orchards C and D, located lower in the valley. The lowest trap catches for the southern orchards were usually found in orchard D, which has no adjacent wild land. Abundance of WFT on the sticky cards in the northern orchards was generally lower than for the southern orchards.

For patterns of flight within orchards and within areas of wild land see below under "Movement of thrips in wild lands" and "Movement of thrips in orchard interiors".



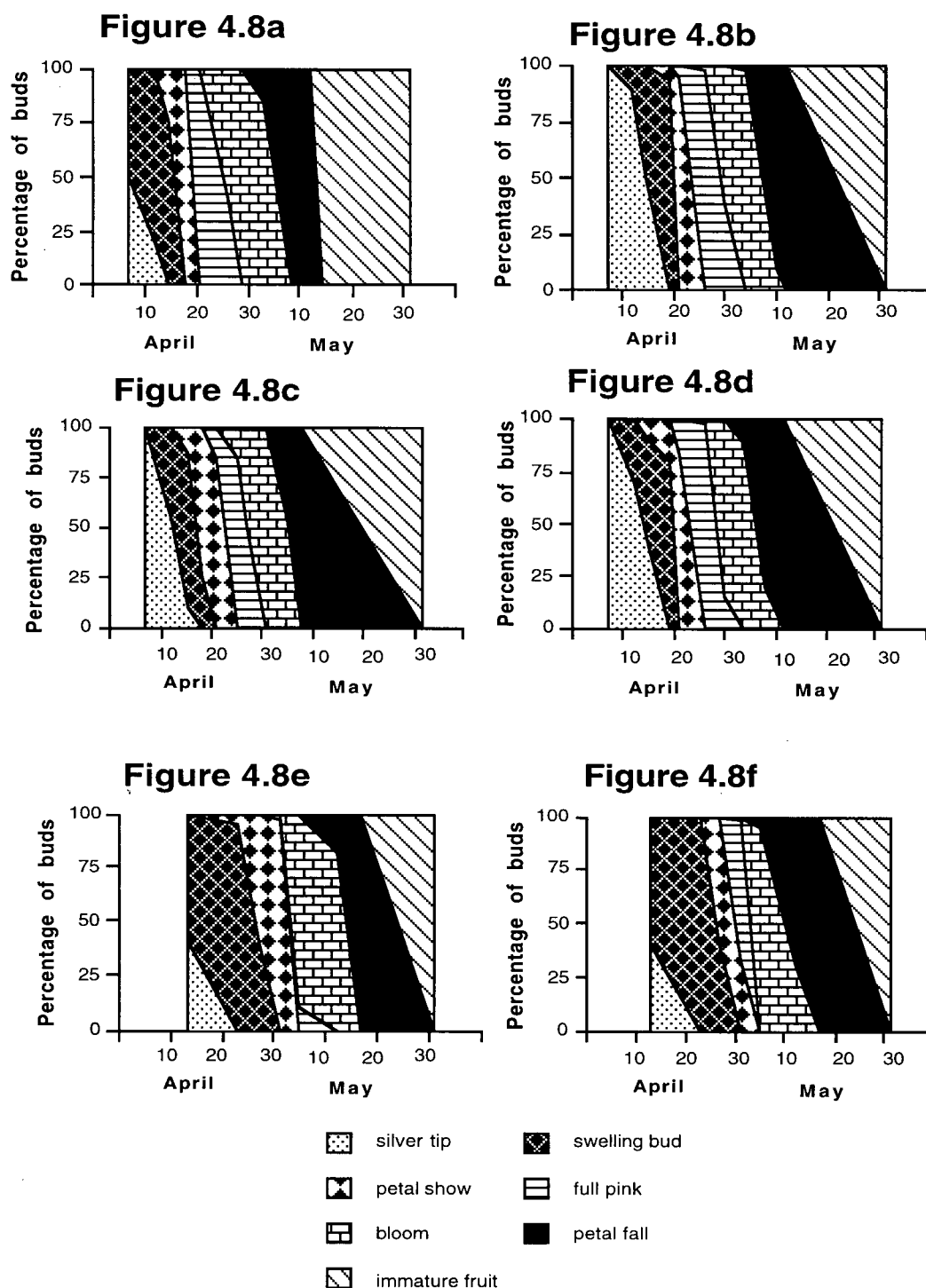
**Table 4.1** Statistics from ANOVA /Kruskal Wallis comparing the densities of WFT collected per post among the orchards A, B, C, D, E and F for each of the relevant dates of sticky card collection between 22 April and 1 June 1993.

| Approx. date of collection | Data transformation | Test statistic | df   | P     | Order of significance |
|----------------------------|---------------------|----------------|------|-------|-----------------------|
| 22/4                       | log(x+1)            | F=16.924       | 4,55 | 0.000 | A=C=E>B=D             |
| 26/4                       | log(x+1)            | F=41.306       | 4,54 | 0.000 | A=B>D=E=C             |
| 30/4                       | none                | KW=33.403      | 4    | 0.000 | C=E=B>D=A             |
| 3/5                        | none                | KW=30.06       | 3    | 0.000 | B=A=C>D               |
| 10/5                       | log(x+1)            | F=11.355       | 5,64 | 0.000 | B=A=D=C>F=E           |
| 14/5                       | $x^{0.5}$           | F=97.769       | 3,43 | 0.000 | B>C>E=F               |
| 23/5                       | none                | KW=60.458      | 5    | 0.000 | B=A>C>D>F=E           |
| 1/6                        | none                | F=7.808        | 5,64 | 0.000 | B=A=F=C>D=E           |

### Nectarine Flower and Ground cover development

Bud development in Orchard A began earliest. The swollen buds began to show petal by 15 April, were at full pink by 21 April, and full bloom (taken as the date when 50% of the orchard is in bloom) occurred within the next two or three days (Figure 4.8a). The other 3 orchards near Cawston were at full bloom by 1 May (Figures 4.8b-d)). Development in the 2 northern orchards was delayed in comparison to the southern orchards, such that full bloom did not occur in these orchards until 5 May (Figures 4.8e,f). Larvae of the first generation appeared beginning on 1 May and peaked around 8 May in the southern orchards. They did not appear in significant densities in the northern orchards until 12 May (Table 4.2).

All orchards had a basic ground cover of orchard grass (*Dactylis glomerata* L.), but differed in the density of dandelions, which were particularly dense in orchard B and sparse in orchard D. Dandelions were present in moderate densities in orchard A and low densities in orchard C until 8 May after which time they went to seed and were then



**Figure 4.8a-f** Development of nectarine buds on trees in orchards A-F. Data are the percentage of buds at each of seven developmental stages (silver tip, swelling bud, petal show, full pink, bloom, petal fall and immature fruit) as assessed from each of 8-15 sample trees every few days between 8 April and 1 June 1993.

removed by mowing. Similarly, they were present on the orchard floor in orchard B in high densities until 10 May .

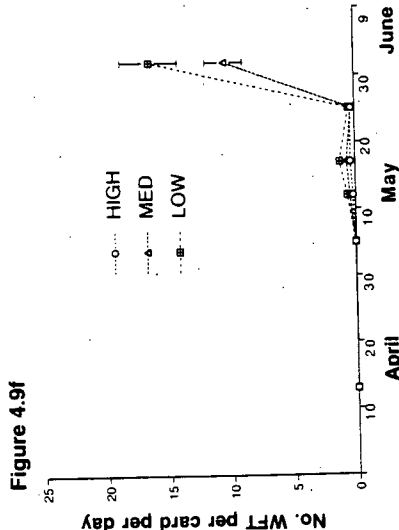
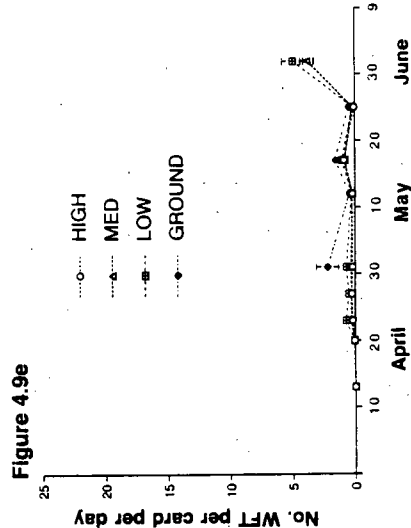
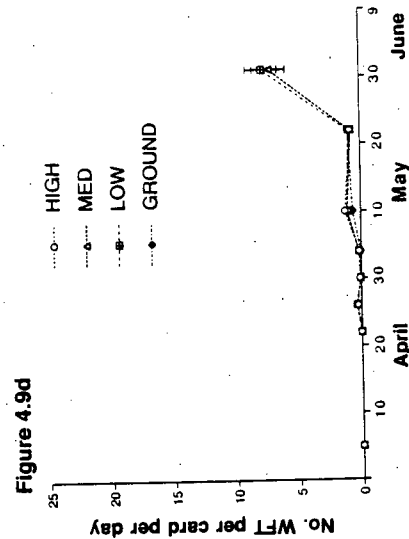
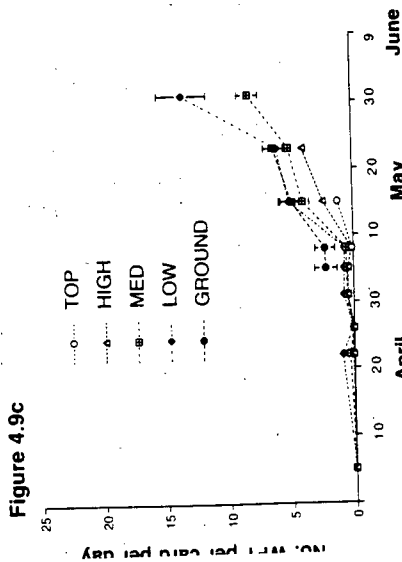
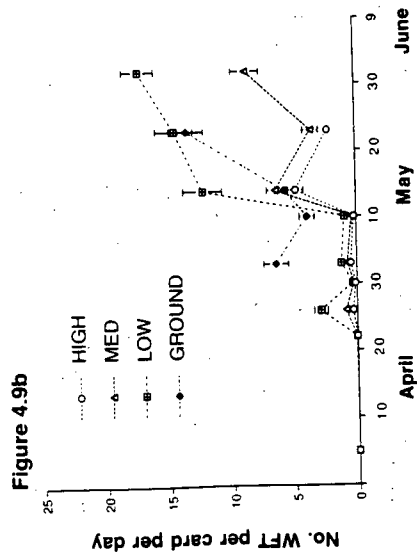
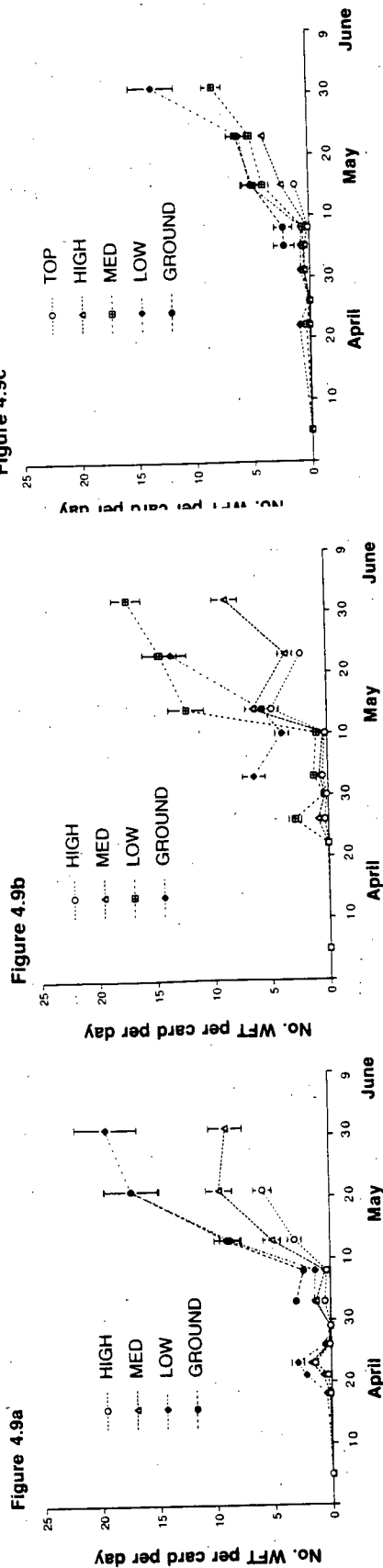
**Table 4.2** Phenology of bud development in the 6 orchards, A, B, C, D, E & F used for the study showing the dates of occurrence of petal show, pink, bloom and petal fall.

| <b>Orchard</b> | <b>Petal show</b> | <b>Pink</b> | <b>Bloom</b> | <b>Petal Fall</b> |
|----------------|-------------------|-------------|--------------|-------------------|
| <b>A</b>       | 15 April          | 21 April    | 23 April     | 6 May             |
| <b>B</b>       | 21 April          | 26 April    | 1 May        | 8 May             |
| <b>C</b>       | 17 April          | 23 April    | 1 May        | 8 May             |
| <b>D</b>       | 20 April          | 26 April    | 1 May        | 8 May             |
| <b>E</b>       | 27 April          | 2 May       | 5 May        | 16 May            |
| <b>F</b>       | 27 April          | 1 May       | 5 May        | 15 May            |

### **Height of flight as assessed from orchard peripheral traps**

Using two-way ANOVA to test the differences in WFT caught at the 2-5 different heights, orientation (In versus Out) as well as the interaction term, we found that the height term was significant for all dates except 26 April in orchard A, and that the numbers of WFT were always highest on the lowest cards available (low cards until 3 May, at which time highest densities were found on either ground cards alone (3 & 8 May) or both ground and low cards (13 & 21 May) (Appendix 4.1, Figure 4.9a). Densities were highest on the low cards for the last date of sampling, (31 May), when only low and medium cards were available.

In orchard B, the height factor was significant for every date of sampling, with lower catches on low cards than high on 22 April and 30 April, lowest catches overall on low cards on 26 April, and lowest numbers on ground cards as these became available (3 May and 10 May) (Appendix 4.1, Figure 4.9b). Again, later in the summer, numbers caught on ground cards did not differ from numbers caught on low cards (14 & 23 May).



**Figure 4.9a-f** Number of WFT per sticky card per day caught at each of 3-5 different heights (G, L, M, H and T) on peripheral posts for orchards A-F for several sampling dates between 5 April and 1 June 1993.

As was the case in orchard A, on the final day of sampling (1 June), densities were highest on the low cards (when only low and medium height cards were available).

In orchard C, height was significant all dates except for 1 May (Appendix 4.1, Figure 4.9c). Again, highest densities were found on the lowest cards available for all dates, although there was no difference among the low and ground level cards later in the summer (15 and 23 May). Thus, as the ground cover diversified in late May and grew higher (up to an average height of 0.7m) than the dandelion cover in orchards A, B and C, movement of thrips did not differ significantly between 0.25 and 1m in these orchards.

In orchard D, the height factor was significant only on one date (10 May), with ground cards catching significantly higher numbers of WFT than high cards (Appendix 4.1, Figure 4.9d). In orchard E, although the height factor was significant for most dates, post-hoc tests did not yield straightforward differences (Appendix 4.1, Figure 4.9e). For orchard F, once appreciable numbers of thrips began to move into orchards (from 12 May onwards), these were found to be mainly at the L level (no ground cards were used in this orchard) (Appendix 4.1, Figure 4.9f).

Greater numbers of thrips were caught on the ground cards in orchard B than in the other southern orchards for all those dates when dandelions were in bloom, and lowest numbers were always captured on the ground cards in orchard D (4 May:  $KW=58.82$ ,  $df=3$ ,  $P=0.000$ ; 10 May:  $KW=28.35$ ,  $df=3$ ,  $P=0.000$ ; 13 May:  $KW=8.45$ ,  $df=2$ ,  $P=0.02$ ; 22 May:  $KW=64.93$ ,  $df=3$ ,  $P=0.000$ ) (Table 4.3). Dandelions were found in very high densities in orchard B, and were at low densities in orchard D. By 22 May densities were higher no doubt due to the emergence of the first generation as well as increased temperatures. All orchards had been mown at this time and the dandelions prior to mowing were at seed.

Wind speeds were measured at each of the four different heights in orchard B on several occasions using a hand-held anemometer (Appendix 4.2). Thrips densities were not adjusted dependent upon these wind speeds.

**Table 4.3** Mean number of WFT per ground level card caught per day in the four southern orchards for four dates in May. Means followed by the same letter are not significantly different at the P=0.05 level.

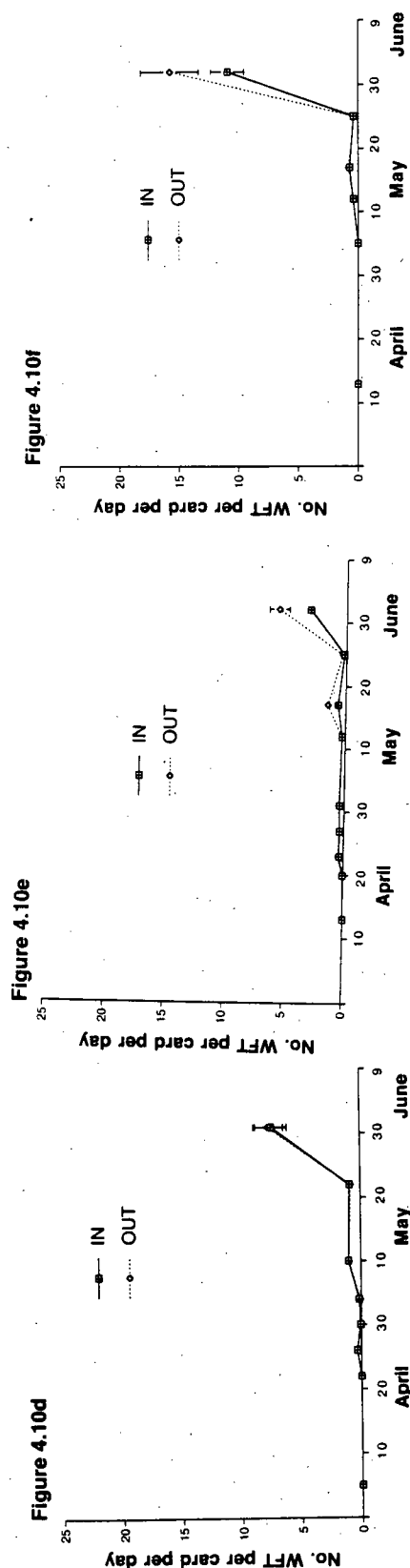
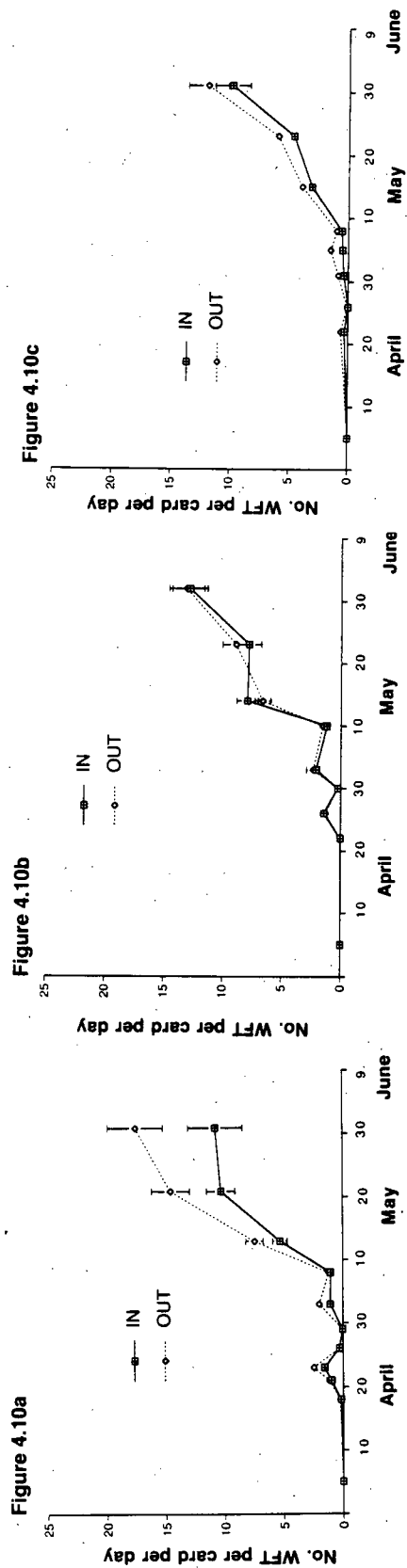
| Date   | Orchard       |               |               |              | State of<br>dandelion<br>bloom |
|--------|---------------|---------------|---------------|--------------|--------------------------------|
|        | A             | B             | C             | D            |                                |
| 4 May  | 3.01(0.48) b  | 6.42(0.98) a  | 2.21(0.89) bc | 0.03(0.02) c | bloom                          |
| 10 May | 2.32(0.37) b  | 3.93(0.60) a  | 2.28(0.79) bc | 0.64(0.12) c | bloom                          |
| 13 May | 8.55(1.13) a  | 5.68(0.73) ab | 4.89(0.86) b  | N/A          | at seed                        |
| 22 May | 17.21(2.32) a | 12.93(1.31) a | 6.25(0.78) b  | 0.98(0.13) c | orchards<br>mown               |

### Orientation of flight

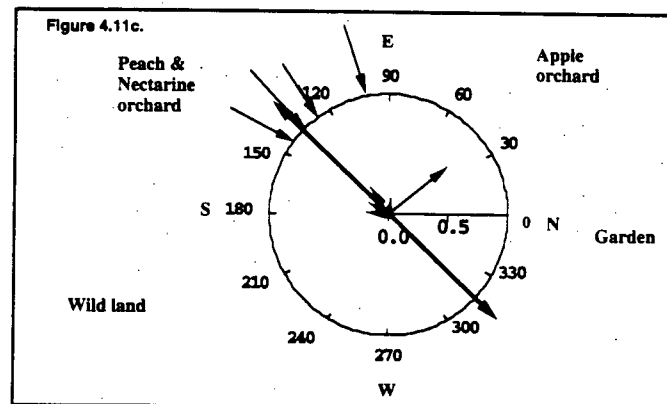
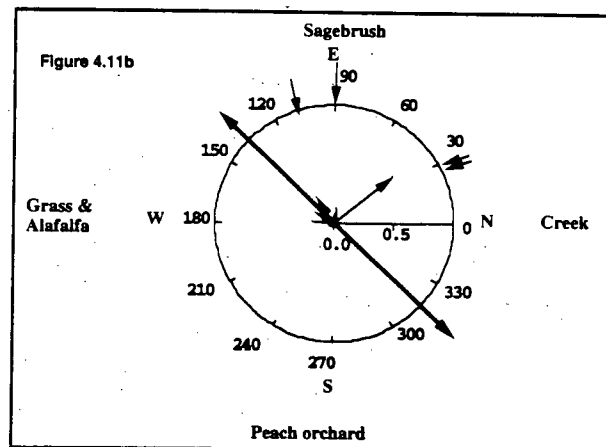
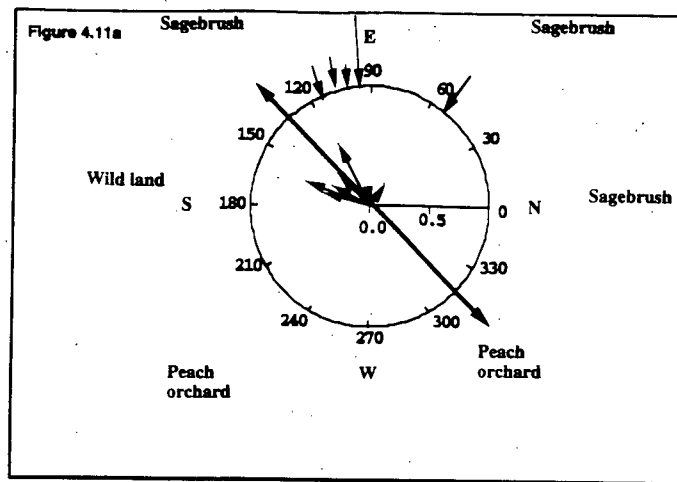
Significant orientation effects were found for some dates in orchards A and C and E, with more thrips flying into rather than out of the orchards for those dates (Figures 4.10a-f). In most cases, however, this factor was not significant (Appendix 4.1).

### Direction of flight

Orchard A lies adjacent to a mountain side and is bounded by wild land along one edge (330° to 120°). Here the mean direction of flight into the orchard was always from the direction of the wild land and varied between posts 4 and 7, (54° to 111°), over the season (Figures 4.11a, 4.2a, Appendix 4.3). In orchard B, the mean direction of flight was also from the wild land which bounded it on one side between 0° and 120° (Figures 4.11b, 4.2b, Appendix 4.3). Mean direction of flight into the orchard in this case varied between 33° and 105°. In orchard C, which is not located near any major patches of sagebrush, most flight occurred from between posts 6 and 8, (108° and 152°). Thus, most flight originated from the direction of an adjacent peach orchard (Figures 4.11c, 4.2c, Appendix 4.3). In the case of orchard D, located in the valley bottom and without any wild

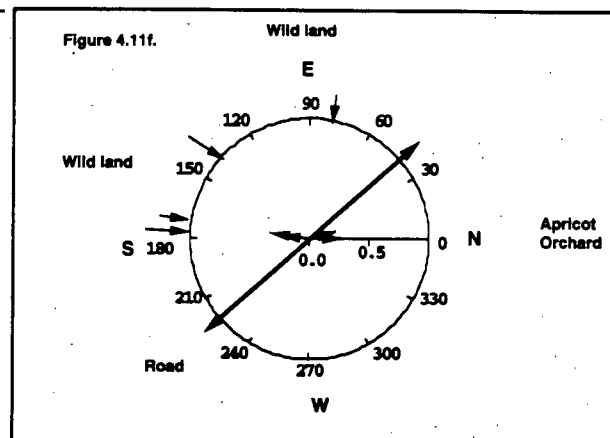
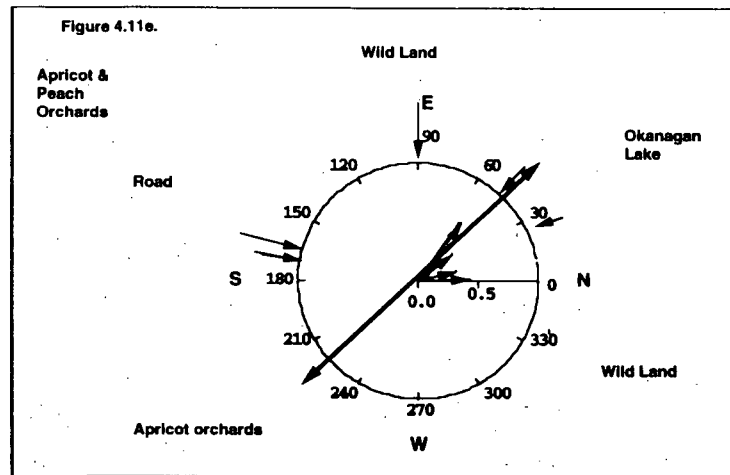
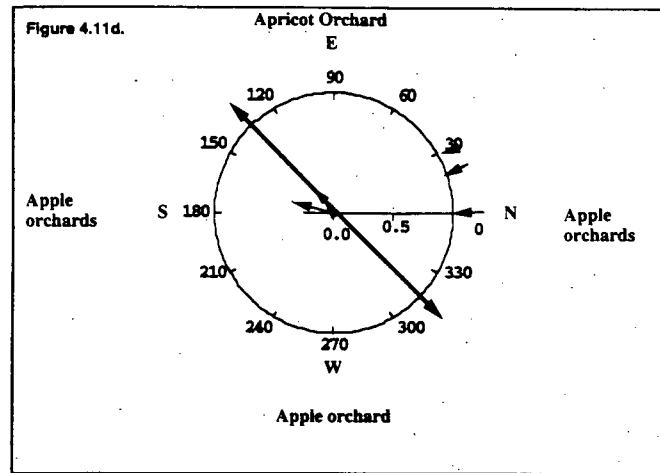


**Figure 4.10a-f** Number of WFT per sticky card per day caught at each of two different orientations (In and Out) on peripheral posts for orchards A-F for several sampling dates between 5 April and 1 June 1993.



**Figure 4.11a-c** Mean direction of flight into and out of orchards A-C as shown using circular statistics. Arrows pointing in towards the centre of circles display mean movement into the orchard for those dates that it was found to be statistically significant (from catches on OUT cards), whereas arrows pointing from the centre of the circle towards the perimeter display mean movement out of the orchard for those dates that it was found to be statistically significant (from catches on IN cards). The length of each vector  $=r$ .  $r$  cannot be  $>1$  which is the radius of the circle. The bidirectional thick arrow shows in each case the main direction of wind flow through the valley.





**Figure 4.11d-f** Mean direction of flight into and out of orchards D-F as shown using circular statistics. Arrows pointing in towards the centre of circles display mean movement into the orchard for those dates that it was found to be statistically significant (from catches on OUT cards), whereas arrows pointing from the centre of the circle towards the perimeter display mean movement out of the orchard for those dates that it was found to be statistically significant (from catches on IN cards). The length of each vector =  $r$ .  $r$  cannot be  $>1$  which is the radius of the circle. The bidirectional thick arrow shows in each case the main direction of wind flow through the valley.

land nearby, the direction of flight of thrips into the orchard rarely departed significantly from randomness (Figures 4.11d, 4.2d, Appendix 4.3). On the two occasions that the mean direction of flight into the orchard was significantly concentrated, thrips were coming from the direction of posts 3-4, ( $3^{\circ}$  and  $16^{\circ}$ ), oriented from an apricot orchard located adjacent to the nectarine block.

In orchard E, the mean direction was significant for six of eight dates and was mainly from the direction between posts 8 and 12, ( $0^{\circ}$  and  $120^{\circ}$ ) (Figures 4.11e, 4.2e, Appendix 4.3). One patch of wild land is located to the north of this orchard and the mean angles recorded reflected the movement from this direction into the orchard. In orchard F, most flight was from the direction between posts 12 and 3 ( $90^{\circ}$  and  $190^{\circ}$ ) (Figures 4.11f, 4.2f, Appendix 4.3), and originated from the patch of wild land which lies on the southeasterly side of this orchard.

Interestingly, the mean direction of thrips flight varied among the four southern orchards and also between the two northern orchards, which suggests that something other than the major wind flow is responsible for affecting the direction of thrips flight.

Winds in the two different valleys predominantly move in two directions, the wind in the Keremeos valley moves either from the NW (towards the SE) or from the SE (towards the NW). In the Summerland valley, wind either moves predominantly from the NE (towards the SW) or from the SW (towards the NE). The flight of thrips into orchards A, B and D did not follow the patterns expected from the predominant wind patterns, although flight of thrips into orchard C could be wind driven, especially as this orchard is located on a bluff and is quite exposed. Flight of thrips into orchard E may be affected by the wind patterns, since most thrips entered this orchard between  $0^{\circ}$  to  $60^{\circ}$  and between  $150^{\circ}$  to  $180^{\circ}$ , which are the predominant directions of wind flow in this valley. This orchard is located close to the cliff edge overlooking Okanagan Lake and is thus highly exposed. However, flight of thrips into orchard F followed a very different pattern, with

most insects flying into the orchard from the direction of the wild land located adjacent to this orchard, and not consistent with the wind patterns in this valley.

The direction of flight of thrips out of the orchards appeared to differ from flight into the orchards for orchards B, D and F, and was also generally more variable in direction in orchards B and F (Figures 4.11b,d,f). Flight of WFT out of orchards B and D appeared likely to be wind driven, unlike flight into these orchards. However, flight of WFT into and out of orchards A, C and E was fairly similar (Figures 4.11a,c&e). Again, flight out of orchards E and C, which are both highly exposed, appeared to be affected by the patterns of wind flow in these two different valleys. Flight out of orchard A appeared to be much more affected by the direction of wind in this valley than was flight into this orchard (Figure 4.11a).

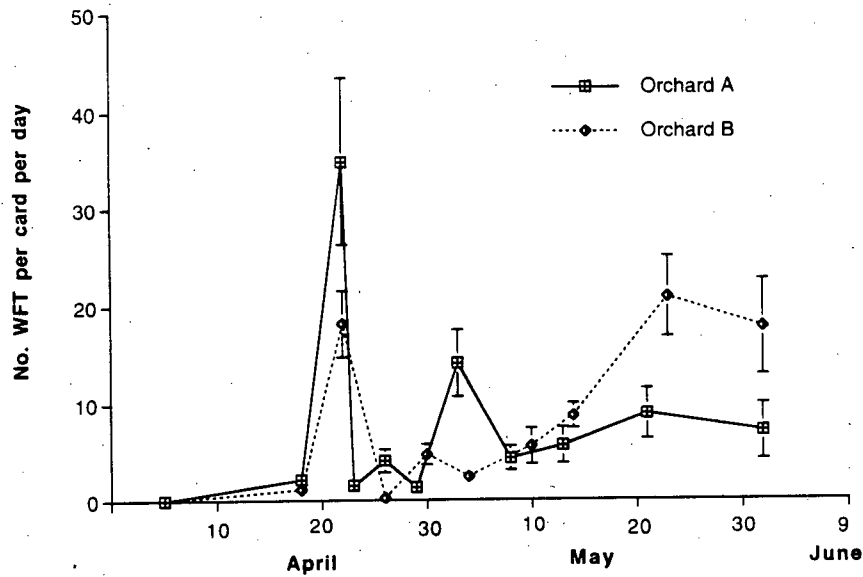
Levels of concentration ( $r$ ) were calculated for each sample date for every orchard (Appendix 4.4). It is apparent that concentration was generally low, not surprising considering the high mobility of this insect.

### **Movement of thrips in wild lands**

Only on 22 April and 3 May were there significantly higher numbers of thrips per card on the "Out" cards as compared with the "In" cards in wild land adjacent to orchard A (Table 4.5). In wild land adjacent to orchard B, there were significantly higher numbers of thrips per "Out" card only on 14 May (Table 4.5).

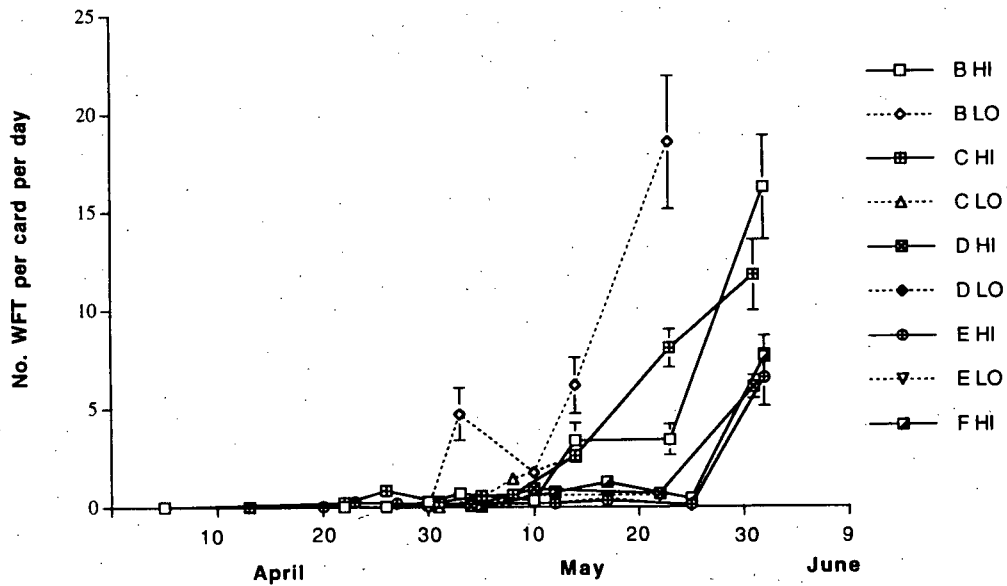
The patterns of flight on posts located within wild land and around the orchards showed fairly good synchrony (see Figures 4.7a,b, 4.12). However, the densities of thrips per card within wild land were much higher in April at the time of thrips emergence from their overwintering sites. Densities were similar between the two areas at the time of the second main peak in May, which occurred when the new generation of adult WFT emerge. Patterns of abundance were generally synchronous in the two different areas of wild land,

Figure 4.12



**Figure 4.12** Numbers of WFT caught per day per card from a total of 16 sticky cards located on eight posts \* two orientations (IN and OUT) in wild land adjacent to orchards A and B from 5 April - 1 June 1993.

Figure 4.13



**Figure 4.13** Number of WFT caught per day per card from sticky cards located on interior posts (1-2 cards from each of 4-6 posts for each of two orientations (IN and OUT)) from orchards B-F from 5 April - 1 June 1993.

although densities of WFT were higher close to orchard A at the time of first emergence, and close to orchard B at the time of the second emergence.

For almost all dates of comparison, there were greater densities of WFT on the "out" cards from wild areas than on "out" peripheral cards in orchards A and B located at a similar level (1 m), with the exception of later in May, when densities were much higher and did not differ between the orchard periphery and wild areas (Table 4.6).

**Table 4.5** Comparison of densities of WFT per card caught on "out" versus "in" sticky cards in wild areas adjacent to orchards A and B. All comparisons used a paired t-test with 7 degrees of freedom. A positive value of T denotes greater densities of WFT on the "out" cards.

| Orchard | Date     | T      | P            |
|---------|----------|--------|--------------|
| A       | 18 April | -0.36  | 0.729        |
| A       | 22 April | 2.363  | <b>0.05</b>  |
| A       | 23 April | 0.205  | 0.844        |
| A       | 24 April | 0.932  | 0.382        |
| A       | 26 April | 1.497  | 0.382        |
| A       | 3 May    | 2.972  | <b>0.021</b> |
| A       | 8 May    | 1.799  | 0.178        |
| A       | 13 May   | 1.637  | 0.146        |
| A       | 21 May   | 0.897  | 0.400        |
| A       | 31 May   | 1.601  | 0.153        |
| B       | 22 April | 1.867  | 0.104        |
| B       | 26 April | 0.832  | 0.433        |
| B       | 30 April | 0.000  | 1.000        |
| B       | 3 May    | -1.503 | 0.177        |
| B       | 10 May   | -1.591 | 0.156        |
| B       | 14 May   | 2.524  | <b>0.04</b>  |
| B       | 1 June   | 2.137  | 0.07         |

**Table 4.6** Comparison of no. of WFT per card for "out" cards in wild lands adjacent to orchards A and B versus "out" peripheral cards in orchards A and B for the low level only. All comparisons were carried out using an independent t-test with 18 degrees of freedom. A negative value of T denotes greater densities of WFT on the "out" cards in wild lands.

| <b>Orchard</b> | <b>Date</b> | <b>T</b> | <b>P</b>     |
|----------------|-------------|----------|--------------|
| <b>A</b>       | 18 April    | -2.828   | <b>0.011</b> |
| <b>A</b>       | 21 April    | -4.965   | <b>0.000</b> |
| <b>A</b>       | 24 April    | 1.685    | 0.109        |
| <b>A</b>       | 26 April    | -3.902   | <b>0.001</b> |
| <b>A</b>       | 3 May       | -4.981   | <b>0.000</b> |
| <b>A</b>       | 8 May       | -3.480   | <b>0.003</b> |
| <b>A</b>       | 13 May      | 0.232    | 0.819        |
| <b>A</b>       | 21 May      | 1.229    | 0.235        |
| <b>A</b>       | 31 May      | 1.345    | 0.195        |
| <b>B</b>       | 22 April    | -6.983   | <b>0.000</b> |
| <b>B</b>       | 26 April    | 1.597    | 0.128        |
| <b>B</b>       | 30 April    | -4.936   | <b>0.000</b> |
| <b>B</b>       | 3 May       | -6.194   | <b>0.000</b> |
| <b>B</b>       | 10 May      | -3.443   | <b>0.003</b> |
| <b>B</b>       | 14 May      | -2.791   | <b>0.012</b> |
| <b>B</b>       | 21 May      | -4.989   | <b>0.000</b> |
| <b>B</b>       | 31 May      | -1.897   | 0.077        |

### **Movement of thrips in orchard interiors**

Patterns of thrips density per card from the interior posts were compared with the density of thrips on the outside posts throughout the season (Figures 4.7a,b, 4.13). The patterns of WFT abundance on the interior cards from all the orchards were very similar to that found on cards from the peripheral posts, with slight increases in late April/ early May

at the time of bloom, and large increases in late May as the first generation emerged. There was also a minor peak in mid-late April which reflected the overwintering generation emergence, but as with the cards on peripheral posts, this was a minor peak and much reduced in comparison with the emergence peak in the wild land at this time.

In orchard B, with a dense mat of dandelions, the density of WFT on the interior ground cards was higher than the interior tree level cards for all sample dates in May, the same pattern as was also found on the sticky cards on the peripheral posts. However, in all other orchards that had interior cards, there was no significant difference in the number of WFT per interior card located at either canopy or ground level for any of the dates when cards were present at both heights (Table 4.7).

**Table 4.7** Comparison of the density of WFT per card located at ground level versus canopy level on interior posts in orchards B, C, D, and E. Statistics shown are for independent t-tests carried out with 22 degrees of freedom for all orchards except E, with 14 degrees of freedom. A positive value for T denotes higher densities of WFT on the ground level cards.

| <b>Orchard</b> | <b>Date</b> | <b>T</b> | <b>P</b>     |
|----------------|-------------|----------|--------------|
| <b>B</b>       | 3 May       | 2.993    | <b>0.007</b> |
| <b>B</b>       | 10 May      | 4.354    | <b>0.000</b> |
| <b>B</b>       | 23 May      | 4.587    | <b>0.000</b> |
| <b>C</b>       | 5 May       | -0.327   | 0.747        |
| <b>C</b>       | 8 May       | 1.459    | 0.159        |
| <b>C</b>       | 14 May      | 0.084    | 0.934        |
| <b>D</b>       | 4 May       | 0.484    | 0.633        |
| <b>D</b>       | 10 May      | -1.808   | 0.084        |
| <b>D</b>       | 22 May      | -0.566   | 0.577        |
| <b>E</b>       | 12 May      | -0.323   | 0.757        |
| <b>E</b>       | 25 May      | -1.131   | 0.273        |

#### 4.4 DISCUSSION

Western flower thrips are by far the most abundant thrips species captured on the sticky cards throughout spring and the early summer in this region. WFT, together with the flower thrips, *Frankliniella tritici* (Fitch), and the soybean thrips, *Neohydatathrips variabilis* (Beach), were the most abundant thrips found in nectarine orchards in Georgia (Yonce *et al.*, 1990a), although the relative abundances varied each year. In peach and nectarine orchards in Pennsylvania, WFT, together with flower thrips, *Frankliniella tritici*, and pear thrips, *Taeniothrips inconsequens* (Uzel), were found to cause injury (Felland *et al.*, 1993b). Other studies of thrips in nectarine orchards in California, Italy, and France also have shown that WFT is common enough and causes serious enough damage to warrant applications of various different insecticides (LaRue *et al.*, 1972; Grasselly *et al.*, 1993; Cravedi *et al.*, 1983; Cravedi and Molinari, 1984). In Greece, damage to nectarines is caused primarily by *Frankliniella intonsa* (Trybom) and *Taeniothrips inconsequens* (Uzel) (Kourmadas *et al.*, 1982), whereas in New Zealand, damage to nectarine is attributed to the New Zealand flower thrips, *Thrips obscuratus* (Crawford) (Thysanoptera:Thripidae) (Teulon and Penman, 1987, 1994, 1996).

The species composition of thrips in this study was similar among areas of wild land and within orchards located both close to and far from areas of wild land, although there did appear to be a higher proportion of the dark morph of WFT caught on sticky cards at the periphery of orchards as compared to those in wild lands. One possibility is that the pale morph is more highly attracted to the blooms than sticky cards than is the dark morph, thereby resulting in an apparent reduction in the relative prevalence of the former as assessed by sticky card catches in orchards. There also tended to be higher proportions of the dark morph in orchard D than in all other orchards. Because of the protected location of orchard D, the thrips caught on sticky cards may be a resident population from within the orchard and the surrounding blocks of trees. This orchard may not receive high levels of



immigration from the vast areas of wild land in the region, from which huge numbers of the pale morph emanate in the early spring. The three species most commonly found on sticky cards: the western flower thrips, *F. occidentalis*; a new and only recently described species, *Thrips fallaciosus* Nakahara; and the Phlaeothripid, *Haplothrips kurdjumovi* Karny, also were identified as the only species found within nectarine blossoms in a separate study (Pearsall, chapter 2). Much lower densities of thrips were captured on sticky cards located in the interior of orchards, as compared to the edges of orchards and in wild lands (Figures 4a-f, 5a-g). This low trap catch within the orchard may result from thrips being more attracted to nectarine and ground cover blooms within the orchard than they are to the sticky cards.

In general, the early stages of nectarine development were delayed in the northern orchards relative to the southern orchards, and mean and maximum temperatures were much higher in the southern than the northern orchards. The lower spring catches of adult WFT in the northern orchards may simply be due to lower flight activity in these orchards in the spring because of the lower temperatures. Climate in the northern part of the valley is buffered by the presence of the large Okanagan Lake: as the lake warms up in May, nighttime temperatures do not get as low in this part of the valley as further south: consequently, the gap between mean and maximum temperatures is much less than for the southern orchards. This may help explain why there appeared to be such high survival of the first generation, as indicated by high densities in late May, particularly in orchard F, despite the much lower densities of overwintering generation adults in this orchard.

The peaks in flight of thrips in wild areas, outside the orchards, and in the interior of orchards differed only slightly. The large peak occurring in the wild regions around the 22 April was not apparent on the sticky cards taken from the interior or orchard posts. Clearly, the bulk of emergence occurs in the wild areas. Thrips appeared to move in higher densities into orchards at this time, which was coincident with the pink stage. The large peaks in numbers of WFT caught during the period after petal fall in all orchards, signifies

the emergence of the first generation, and densities were proportionately larger in the orchards compared to densities before petal fall, than was the case in the wild areas. Egg-laying by WFT was clearly more concentrated within the orchards, which are generally no more than a half acre in area, than in the vast wild areas where there are much fewer available blooms.

Most of the thrips appeared to move into orchards at ground level in the early spring. This may be because low temperatures do not permit the production of thermal updrafts, which can carry thrips to higher levels later in the season. Thus they enter orchards in a series of jumps at ground level. Orchard D was an exception, as thrips moving into this orchard were spread evenly at all four heights throughout the study period. The surrounding trees may alter the flow pattern of the thrips into the orchard. By early May, when the trees had bloomed, thrips moved into the other orchards equally at ground level (25 cm) and at the 1 m level, which is the height of the bottom of the tree canopy. By late May, thrips were still moving into those orchards located close to wild land (A and B) primarily at the ground and low levels, but the movement into orchards lower in the valley (C and D) appeared to be more evenly spread among all heights. This suggests that thrips flying into orchards from the hillsides are moving at the height of 1 m or less which is the approximate height of the sagebrush and other wild land vegetation. However, movement of thrips within orchards, as assessed by catches on the interior sticky cards, showed that thrips were flying equally at canopy level and at ground level in all orchards except for B, where the very high density of dandelions no doubt led to the much higher densities of WFT at ground level than at canopy level. In general, much higher numbers of WFT also were caught at ground level on the post cards at the periphery of this orchard than all the other orchards located in the Similkameen valley. Thus it appears that the presence of a blooming ground cover may have an effect on movement of thrips within orchards. Height differences were less pronounced in orchard F than A and B, although all these orchards were located close to large patches of wild land. Most

movement occurred at the low and ground levels in orchard E when these cards were available, and thus patterns of flight in this orchard were similar to that found in the southern orchards.

There appeared to be spatial differences, with higher densities of WFT in orchards located in the southern parts of the valley as compared with the northern part. However the densities of WFT emerging in orchard F in late May/early June were surprisingly high, considering the low densities of WFT found on sticky cards throughout May in that orchard. This may be due to the generally lower temperatures in the northern orchards, where the proximity of the large Okanagan Lake has a moderating influence on air temperature extremes. Densities of WFT on cards in wild areas were always higher than on cards located at a similar level (1 m) at the periphery of orchards A and B. In general, there were also higher numbers of thrips entering orchards that were located close to patches of wild land, particularly those orchards flanked on one or more sides by the vast tracts of wild land that is located on the hillsides in this region. A previous study also found that orchards on the hillside had higher densities of buds infested by western flower thrips larvae, and higher levels of fruit scarring than orchards that were fully surrounded by other trees, such as orchard D (Pearsall, chapter 2).

Although WFT overwinter within orchards (Pearsall, chapter 2), it appears that many more WFT immigrate from areas of wild land, and thus orchards adjacent to wild areas appear to be most at risk. It would not be possible to predict the occurrence of the spring emergence of thrips without measuring day-degrees. If movement into orchards occurred as one distinct peak, a management strategy at the time of emergence and immigration might be successful if combined with proper forecasting knowledge. However, even though there are distinct peaks of flight, movement into orchards appears to occur as a gradual and continuous process and thus there is a constant stream of insects flying into the orchard. This greatly reduces the likelihood of successful control at this point in the life cycle.

Cho *et al.* (1989) and Puche *et al.* (1993) suggested that adult thrips are unlikely to travel very great distances. Thus, the sources for most thrips immigrating into crops are believed to be nearby areas of wild land and hedgerows adjacent to fields (Chellemi *et al.*, 1994). Southwood (1978) identified two types of insect movement: migratory and trivial (local). The former types of dispersal tend to move the individual insect much greater distances, and often at much higher altitudes than the latter types of dispersal. Employing this definition, we are clearly concerned with trivial flight in this study. If the speculations by Cho *et al.* (1989) and Puche *et al.* (1993) are true, then it is likely that the bulk of WFT entering orchards throughout the spring and early summer are derived from the wild areas of weeds, wildflowers and sagebrush that are located adjacent to many of the orchards. Indeed, the fact that mean direction of movement varied among orchards, sometimes opposite in direction even in closely positioned orchards (such as E and F), suggests that the type of vegetation surrounding an orchard clearly plays an important role in the direction of dispersal of these insects. In general, WFT moved into orchards from the direction of patches of wild land, regardless of the wind flow patterns, but moved out of orchards in accordance with the dominant wind patterns. Orchard D appeared to be in a fairly protected situation, surrounded by trees. It not only received generally low densities of WFT, but these insects showed neither directional movement nor height differential in flight.

Lewis (1981) suggested that the best method of sampling dispersive phases of insects is to use estimates of the pest population from various trapping techniques. Traps such as sticky cards are useful for detection of the first presence of a pest and thus for the timing of application of control measures (Lewis, 1981). However, it is possible that different species of thrips may be attracted differentially to these sticky cards: some species may even be repelled by the colour that I chose to use. Some species of thrips may be less mobile than others, and thus, less likely to be caught on such traps. Therefore, the density of thrips caught on sticky cards may not be a true reflection of their absolute abundance

within an orchard. However, these numbers may be a reflection of the average proportion of different species that are in flight, or are being carried by air currents. It is generally believed that thrips are unable to direct the course of their flight in anything stronger than the slightest breeze. However, at very low wind speeds it is possible that they may have control over their direction. The range of air-speeds for thrips probably varies between 10 cm per second for small Terebrantia up to 50 cm per second for the largest Tubulifera (Lewis, 1973). For medium sized Terebrantia such as WFT, the mean flight speed is probably something in the order of 15 cm per second. At higher wind speeds, however, it is likely that the thrips cannot direct their direction of flight and may be impacted onto cards. In this case, the density of thrips at any particular height is a measure of the density of this 'aerial plankton'. It is difficult to make a correction for wind speed as winds would be variable over time and sticky cards were placed out for a number of days. However, on the occasions that wind speeds were measured using a hand-held anemometer, wind speed at the high and medium card levels (1.75 and 1.25 m) were always much higher than the speeds at the low and ground levels (75 and 25 cm). Thus, the densities at the high and medium levels would be even lower relative to those at low and ground levels if we were to correct for wind speed. It is likely that thrips at ground level are simply hopping onto cards, and numbers are substantially elevated at this level, not because there are a lot of thrips *in flight* at this level, but because there is in general a high density of thrips in the ground cover blooms. However, the high counts at the lower levels of sticky cards suggest that most movement of WFT, at least in orchards, is close to ground level. This disagrees with the results of several other studies using sticky cards to assess the relative density of WFT which have shown that the greatest numbers were caught on sticky cards placed just above the crop canopy (e.g. Brodsgaard, 1989b; Gillespie and Vernon, 1990).

The lack of orientation effects found in this study may be due to the fact that wind may form eddies around a flat surface (Lewis, 1959) and thus thrips initially approaching one side of a sticky card, may be carried around the edges of cards by eddies so that they

become trapped on the opposite side from which they originated. However, the significant variation in directional movement into and out of orchards, exemplified by cases in which thrips appeared to enter an orchard mainly from one direction, but leave mainly in another, suggests that thrips may be oriented in their movement.

Temperature more than any other physical factor is known to influence aerial dispersal of both winged and nonwinged invertebrates (Taylor, 1963). WFT were caught on sticky cards as soon as the mean temperature reached 9°C and the maximum temperature reached 15°C. A more intensive study of the periodicity of flight of thrips found that flight commenced as soon as the temperature reached 16°C (Pearsall, chapter 5). Populations of WFT in flight appeared to increase rapidly in mid-May as the temperatures rose. Yonce *et al.* (1990a) suggested that low rainfall led to higher abundances of flower thrips in nectarine orchards. The year that this study was conducted, 1993, was a particularly cool and wet year. However, I am unable to ascertain the relative importance of precipitation and temperature as this study was carried out for only one year. In addition, the abundance of weed and wildflowers is very high in May, such that this factor confounds with that of climate.

In conclusion, local movement of emerging thrips into orchards in the early spring occurs primarily at ground level, and is greatest in those orchards located adjacent to wild land. Western flower thrips are by far the most abundant species of thrips trapped on sticky cards, although there are variations in the proportions of the dark and pale colour morphs, with more pale morph females caught in areas of wild land, and more dark morph females caught in orchards that were not located adjacent to wild land. I found evidence that thrips can direct their movement into orchards: perhaps by a combination of 'hopping' from plant to plant and remaining at ground level, WFT can avoid the effects of higher wind speeds at higher levels above ground level, and thus have some control of their direction.

## 4.5 APPENDICES

**Appendix 4.1** Statistics for two-way ANOVA assessing the effects of height of sticky cards above ground, orientation of sticky cards (In- or Out-facing) and the interaction term on densities of WFT caught for orchards A-F for each date of sticky card collection between 18 April and 1 June.

| Orch | Date     | Height |       | Orientation |       | Interaction |       | df       |
|------|----------|--------|-------|-------------|-------|-------------|-------|----------|
|      |          | F      | P     | F           | P     | F           | P     |          |
| A    | 18 April | 4.609  | 0.016 | 0.672       | 0.415 | 0.200       | 0.819 | 2,1,2,66 |
| A    | 21 April | 10.069 | 0.000 | 0.295       | 0.589 | 0.158       | 0.854 | 2,1,2,66 |
| A    | 23 April | 3.594  | 0.033 | 3.464       | 0.067 | 1.681       | 0.194 | 2,1,2,66 |
| A    | 26 April | 2.473  | 0.092 | 0.020       | 0.888 | 3.850       | 0.026 | 2,1,2,66 |
| A    | 3 May    | 16.664 | 0.000 | 12.631      | 0.001 | 4.865       | 0.004 | 3,1,3,88 |
| A    | 8 May    | 16.992 | 0.000 | 0.620       | 0.433 | 0.092       | 0.964 | 3,1,3,88 |
| A    | 13 May   | 11.269 | 0.000 | 5.772       | 0.018 | 0.072       | 0.975 | 3,1,3,87 |
| A    | 21 May   | 12.312 | 0.000 | 9.044       | 0.003 | 0.369       | 0.776 | 3,1,3,88 |
| A    | 31 May   | 12.284 | 0.001 | 5.196       | 0.028 | 0.268       | 0.607 | 1,1,1,44 |
| B    | 22 April | 6.472  | 0.003 | 0.690       | 0.160 | 0.852       | 0.160 | 2,1,2,66 |
| B    | 26 April | 14.14  | 0.000 | 0.092       | 0.763 | 0.125       | 0.883 | 2,1,2,66 |
| B    | 30 April | 4.012  | 0.023 | 0.429       | 0.515 | 0.464       | 0.631 | 2,1,2,66 |
| B    | 3 May    | 29.673 | 0.000 | 0.221       | 0.639 | 0.265       | 0.850 | 3,1,3,88 |
| B    | 10 May   | 32.158 | 0.000 | 1.261       | 0.265 | 1.226       | 0.305 | 3,1,3,88 |
| B    | 14 May   | 12.312 | 0.000 | 1.868       | 0.175 | 1.635       | 0.187 | 3,1,3,88 |
| B    | 23 May   | 35.775 | 0.000 | 0.932       | 0.364 | 0.470       | 0.704 | 3,1,3,88 |
| B    | 1 June   | 4.648  | 0.037 | 1.008       | 0.321 | 0.690       | 0.441 | 1,1,1,44 |
| C    | 22 April | 5.654  | 0.005 | 2.056       | 0.156 | 0.666       | 0.517 | 2,1,2,66 |
| C    | 1 May    | 1.559  | 0.218 | 8.46        | 0.005 | 1.439       | 0.245 | 2,1,2,66 |
| C    | 5 May    | 3.319  | 0.023 | 4.940       | 0.029 | 2.059       | 0.111 | 3,1,3,88 |

|          |          |        |       |       |       |       |       |           |
|----------|----------|--------|-------|-------|-------|-------|-------|-----------|
| <b>C</b> | 8 May    | 5.633  | 0.000 | 1.572 | 0.213 | 0.934 | 0.447 | 4,1,4,110 |
| <b>C</b> | 15 May   | 7.904  | 0.000 | 2.362 | 0.127 | 1.417 | 0.233 | 4,1,4,110 |
| <b>C</b> | 23 May   | 3.674  | 0.015 | 5.673 | 0.019 | 0.817 | 0.488 | 3,1,3,88  |
| <b>C</b> | 31 May   | 5.986  | 0.018 | 0.905 | 0.347 | 0.004 | 0.949 | 1,1,1,44  |
| <b>D</b> | 22 April | 0.038  | 0.963 | 0.343 | 0.560 | 0.114 | 0.892 | 2,1,2,66  |
| <b>D</b> | 26 April | 0.418  | 0.660 | 0.000 | 1.000 | 0.968 | 0.385 | 2,1,2,66  |
| <b>D</b> | 30 April | 1.567  | 0.216 | 0.271 | 0.604 | 0.362 | 0.698 | 2,1,2,66  |
| <b>D</b> | 4 May    | 2.225  | 0.091 | 1.521 | 0.221 | 0.116 | 0.952 | 3,1,3,88  |
| <b>D</b> | 10 May   | 2.728  | 0.049 | 0.026 | 0.880 | 0.008 | 0.999 | 3,1,3,88  |
| <b>D</b> | 22 May   | 0.535  | 0.660 | 0.360 | 0.550 | 1.086 | 0.359 | 3,1,3,88  |
| <b>D</b> | 31 May   | 0.093  | 0.762 | 0.022 | 0.882 | 0.416 | 0.522 | 1,1,1,44  |
| <b>E</b> | 20 April | 0.171  | 0.843 | 0.880 | 0.352 | 1.393 | 0.255 | 2,1,2,66  |
| <b>E</b> | 23 April | 5.8    | 0.005 | 0.655 | 0.421 | 0.411 | 0.665 | 2,1,2,66  |
| <b>E</b> | 27 April | 4.654  | 0.013 | 0.458 | 0.501 | 0.322 | 0.726 | 2,1,2,66  |
| <b>E</b> | 1 May    | 4.31   | 0.017 | 0.016 | 0.899 | 0.306 | 0.738 | 2,1,2,66  |
| <b>E</b> | 12 May   | 2.978  | 0.036 | 0.022 | 0.883 | 1.542 | 0.229 | 3,1,3,88  |
| <b>E</b> | 17 May   | 2.468  | 0.067 | 5.125 | 0.026 | 0.253 | 0.859 | 3,1,3,88  |
| <b>E</b> | 25 May   | 4.951  | 0.003 | 3.266 | 0.074 | 0.321 | 0.81  | 3,1,3,88  |
| <b>E</b> | 1 June   | 1.46   | 0.233 | 7.733 | 0.008 | 0.468 | 0.498 | 1,1,1,44  |
| <b>F</b> | 5 May    | 0.208  | 0.813 | 0.052 | 0.820 | 0.676 | 0.512 | 2,1,2,66  |
| <b>E</b> | 12 May   | 8.684  | 0.000 | 0.154 | 0.696 | 0.069 | 0.934 | 2,1,2,66  |
| <b>F</b> | 17 May   | 10.089 | 0.000 | 0.309 | 0.580 | 0.178 | 0.837 | 2,1,2,66  |
| <b>F</b> | 25 May   | 2.124  | 0.117 | 0.319 | 0.574 | 0.007 | 0.993 | 2,1,2,66  |
| <b>F</b> | 1 June   | 5.285  | 0.026 | 3.484 | 0.069 | 0.968 | 0.330 | 1,1,1,44  |



**Appendix 4.2** Wind speeds as assessed on different occasions in orchard B using a hand held anemometer. Speed is measured in kilometres per hour at four randomly chosen posts for each date.

| <b>Date</b>     | <b>Height</b> | <b>post (1)</b> | <b>post (2)</b> | <b>post(3)</b> | <b>post(4)</b> |
|-----------------|---------------|-----------------|-----------------|----------------|----------------|
| <b>30 April</b> | 2m            | 8-10            | 10-14           | 10-16          | 8-12           |
| <b>30 April</b> | 1.5m          | 8-10            | 10-14           | 10-16          | 8-12           |
| <b>30 April</b> | 1m            | 6-8             | 10-14           | 10-16          | 8-12           |
| <b>30 April</b> | 0.25m         | 4-6             | 4-8             | 6-10           | 4-8            |
| <b>4 May</b>    | 2m            | 7-13            | 0-10            | 8-13           | 4-15           |
| <b>4 May</b>    | 1.5m          | 8-10            | 0-10            | 6-9            | 2-10           |
| <b>4 May</b>    | 1m            | 8-10            | 0-8             | 6-9            | 2-7            |
| <b>4 May</b>    | 0.25m         | 0-7             | 0-4             | 0-6            | 0-4            |
| <b>14 May</b>   | 2m            | 12-16           | 12-16           | 12-14          | 9-12           |
| <b>14 May</b>   | 1.5m          | 10-13           | 10-13           | 10-11          | 7-9            |
| <b>14 May</b>   | 1m            | 10-13           | 10-13           | 8-9            | 7-10           |
| <b>14 May</b>   | 0.25m         | 6-9             | 6-9             | 6-8            | 0-5            |
| <b>23 May</b>   | 2m            | 9-12            | 11-15           | 13             | 13             |
| <b>23 May</b>   | 1.5m          | 9-12            | 11-15           | 13             | 13             |
| <b>23 May</b>   | 1m            | 9-12            | 9-11            | 7-11           | 6-9            |
| <b>23 May</b>   | 0.25m         | 0-3             | 0-2             | 0-4            | 4-6            |

**Appendix 4.3** 20 April counts for orchard E, and May 5 counts for orchard F are for pooled data (In and Out cards pooled) only since total number of thrips (n) was particularly low on those dates.

| Orch | Date     | IN cards                         |        |        |      | OUT cards                        |        |        |      |
|------|----------|----------------------------------|--------|--------|------|----------------------------------|--------|--------|------|
|      |          | mean<br>angle<br>( $\vartheta$ ) | Z      | P      | n    | mean<br>angle<br>( $\vartheta$ ) | Z      | P      | n    |
| A    | 18 April | 117.95                           | 28.26  | <0.001 | 84   | 94.3                             | 41.50  | <0.001 | 113  |
| A    | 21 April | 159.66                           | 34.23  | <0.001 | 105  | 110.6                            | 11.34  | <0.001 | 126  |
| A    | 23 April | 163.52                           | 18.35  | <0.001 | 113  | 54.1                             | 25.69  | <0.001 | 177  |
| A    | 3 May    | 151.34                           | 26.59  | <0.001 | 204  | 96.2                             | 13.79  | <0.001 | 382  |
| A    | 8 May    | 134.88                           | 34.86  | <0.001 | 244  | 102.7                            | 20.16  | <0.001 | 287  |
| A    | 13 May   | 170.33                           | 56.70  | <0.001 | 1238 | 69.9                             | 2.18   | <0.2   | 1785 |
| A    | 21 May   | 131.32                           | 212.61 | <0.001 | 3950 | 62.4                             | 134.68 | <0.001 | 5606 |
| A    | 31 May   | 169.24                           | 98.29  | <0.001 | 2585 | 58.8                             | 155.20 | <0.001 | 4210 |
| B    | 26 April | 38.73                            | 80.5   | <0.001 | 206  | 20.22                            | 9.95   | <0.001 | 188  |
| B    | 30 April | 64.63                            | 0.87   | <0.5   | 38   | 132.6                            | 1.22   | <0.5   | 32   |
| B    | 3 May    | 79.87                            | 4.75   | <0.01  | 302  | 104.7                            | 34.51  | <0.001 | 337  |
| B    | 10 May   | 124.06                           | 26.90  | <0.001 | 398  | 88.99                            | 66.61  | <0.001 | 514  |
| B    | 14 May   | 176.97                           | 46.67  | <0.001 | 1524 | 32.5                             | 7.94   | <0.001 | 1272 |
| B    | 23 May   | 162.06                           | 27.97  | <0.001 | 3305 | 35.8                             | 4.99   | <0.01  | 3847 |
| B    | 1 June   | 150.96                           | 93.88  | <0.001 | 2773 | 12.37                            | 1.14   | <0.5   | 2837 |
| C    | 22 April | 128.65                           | 67.26  | <0.001 | 190  | 134.22                           | 165.39 | <0.001 | 374  |
| C    | 1 May    | 106.84                           | 7.22   | <0.001 | 67   | 124.42                           | 42.42  | <0.001 | 151  |
| C    | 5 May    | 150.2                            | 10.02  | <0.001 | 93   | 152.1                            | 105.03 | <0.001 | 286  |
| C    | 8 May    | 134.71                           | 36.90  | <0.001 | 86   | 108.33                           | 62.31  | <0.001 | 176  |
| C    | 15 May   | 137.42                           | 39.36  | <0.001 | 1094 | 109.45                           | 237.83 | <0.001 | 1647 |
| C    | 23 May   | 50.03                            | 0.44   | >0.5   | 1786 | 125.29                           | 9.10   | <0.001 | 2295 |

|          |          |        |        |                  |      |        |        |                  |      |
|----------|----------|--------|--------|------------------|------|--------|--------|------------------|------|
| <b>C</b> | 31 May   | 127.5  | 79.77  | <b>&lt;0.001</b> | 1894 | 124.01 | 83.53  | <b>&lt;0.001</b> | 2291 |
| <b>D</b> | 26 April | 57.49  | 2.86   | <b>&lt;0.1</b>   | 49   | 43.36  | 1.48   | <b>&lt;0.5</b>   | 49   |
| <b>D</b> | 10 May   | 128.17 | 5.62   | <b>&lt;0.005</b> | 292  | 160.87 | 1.99   | <b>&lt;0.2</b>   | 289  |
| <b>D</b> | 22 May   | 179.44 | 31.31  | <b>&lt;0.001</b> | 505  | 2.86   | 30.71  | <b>&lt;0.001</b> | 476  |
| <b>D</b> | 31 May   | 165.6  | 198.49 | <b>&lt;0.001</b> | 1602 | 15.73  | 11.69  | <b>&lt;0.001</b> | 1656 |
| <b>E</b> | 20 April | 89.9   | 8.10   | <b>&lt;0.001</b> | 32   |        |        |                  |      |
| <b>E</b> | 23 April | 55.43  | 14.09  | <b>&lt;0.001</b> | 39   | 169.74 | 5.99   | <b>&lt;0.005</b> | 50   |
| <b>E</b> | 27 April | 53.73  | 16.00  | <b>&lt;0.001</b> | 43   | 137.73 | 2.29   | <b>&lt;0.2</b>   | 52   |
| <b>E</b> | 1 May    | 38.28  | 7.00   | <b>&lt;0.001</b> | 54   | 97.55  | 1.42   | <b>&lt;0.5</b>   | 56   |
| <b>E</b> | 12 May   | 1.81   | 27.74  | <b>&lt;0.001</b> | 150  | 46.26  | 16.37  | <b>&lt;0.001</b> | 155  |
| <b>E</b> | 17 May   | 44.94  | 7.12   | <b>&lt;0.001</b> | 147  | 164.07 | 94.38  | <b>&lt;0.001</b> | 312  |
| <b>E</b> | 25 May   | 157.07 | 0.11   | <b>&gt;0.5</b>   | 69   | 168.81 | 22.50  | <b>&lt;0.001</b> | 124  |
| <b>E</b> | 1 June   | 13.83  | 57.54  | <b>&lt;0.001</b> | 522  | 20.87  | 63.54  | <b>&lt;0.001</b> | 962  |
| <b>F</b> | 5 May    | 171.9  | 3.33   | <b>&lt;0.05</b>  | 52   |        |        |                  |      |
| <b>E</b> | 12 May   | 15.58  | 5.62   | <b>&lt;0.005</b> | 110  | 127.37 | 3.53   | <b>&lt;0.05</b>  | 101  |
| <b>F</b> | 17 May   | 0.99   | 8.72   | <b>&lt;0.001</b> | 128  | 146.42 | 20.04  | <b>&lt;0.001</b> | 144  |
| <b>F</b> | 25 May   | 171.85 | 11.65  | <b>&lt;0.001</b> | 111  | 83.15  | 6.44   | <b>&lt;0.002</b> | 99   |
| <b>F</b> | 1 June   | 173.62 | 100.98 | <b>&lt;0.001</b> | 1813 | 175.32 | 352.17 | <b>&lt;0.001</b> | 2658 |

**Appendix 4.4** Measure of concentration ( $r$ ) as given by Raleigh's test of mean angles for thrips catches for IN cards, OUT cards and IN and OUT cards pooled (for those dates where numbers of WFT were too low to permit calculation of mean angles for the two orientations separately (taken as total  $n < 52$ ).)

| Orchard | Date     | IN cards | OUT cards | IN and OUT<br>cards pooled |
|---------|----------|----------|-----------|----------------------------|
| A       | 18 April | 0.58     | 0.61      |                            |
| A       | 21 April | 0.57     | 0.30      |                            |
| A       | 23 April | 0.60     | 0.38      |                            |
| A       | 3 May    | 0.36     | 0.19      |                            |
| A       | 8 May    | 0.38     | 0.27      |                            |
| A       | 13 May   | 0.21     | 0.19      |                            |
| A       | 21 May   | 0.15     | 0.15      |                            |
| A       | 31 May   | 0.09     | 0.19      |                            |
| B       | 26 April | 0.63     | 0.23      |                            |
| B       | 30 April | 0.15     | 0.19      |                            |
| B       | 3 May    | 0.13     | 0.32      |                            |
| B       | 10 May   | 0.26     | 0.36      |                            |
| B       | 14 May   | 0.18     | 0.08      |                            |
| B       | 23 May   | 0.09     | 0.04      |                            |
| B       | 1 June   | 0.18     | 0.02      |                            |
| C       | 22 April | 0.60     | 0.67      |                            |
| C       | 1 May    | 0.39     | 0.53      |                            |
| C       | 5 May    | 0.33     | 0.61      |                            |
| C       | 8 May    | 0.66     | 0.59      |                            |
| C       | 15 May   | 0.19     | 0.38      |                            |
| C       | 23 May   | 0.02     | 0.06      |                            |
| C       | 31 May   | 0.31     | 0.31      |                            |
| D       | 26 April | 0.24     | 0.17      |                            |

|   |          |      |      |      |
|---|----------|------|------|------|
| D | 10 May   | 0.14 | 0.08 |      |
| D | 22 May   | 0.25 | 0.25 |      |
| D | 31 May   | 0.35 | 0.08 |      |
| E | 20 April |      |      | 0.50 |
| E | 23 April | 0.60 | 0.35 |      |
| E | 27 April | 0.41 | 0.21 |      |
| E | 1 May    | 0.36 | 0.16 |      |
| E | 12 May   | 0.43 | 0.33 |      |
| E | 17 May   | 0.22 | 0.55 |      |
| E | 25 May   | 0.04 | 0.43 |      |
| E | 1 June   | 0.33 | 0.26 |      |
| F | 5 May    |      |      | 0.25 |
| E | 12 May   | 0.23 | 0.19 |      |
| F | 17 May   | 0.26 | 0.37 |      |
| F | 25 May   | 0.32 | 0.26 |      |
| F | 1 June   | 0.24 | 0.36 |      |

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## CHAPTER 5

### SPATIAL AND TEMPORAL DISTRIBUTION PART II

#### Daily Flight Activity of a Highly Mobile Insect, the Western Flower Thrips

**ABSTRACT:** Hourly flight patterns of western flower thrips (WFT) were assessed over a twenty-four hour period in two orchards located in the Similkameen Valley, British Columbia, on 13 separate occasions between March and October 1994. The numbers of WFT (male or female, dark or pale morphs) trapped per hour at eight heights (0.25, 0.50, 0.75, 1.00, 1.25, 1.50, 1.75, & 2.00 m) for 31 March - 19 May, and at four heights (0.25, 0.75, 1.25, & 1.75 m) for 30 May - 9 October were compared with temperature, wind speed and the stage of development of flower buds of nectarines and ground cover. Data on flight were taken within the orchards, at the orchard edge (border of orchard and wild land), and within the adjacent areas of wild land. Western flower thrips flew within defined temperature and wind speed limits, although the effect of wind speed varied with height of flight. Height of flight was affected by both the prevalent vegetation and temperature, with mean height of flight tending to increase linearly with temperature. Most movement of WFT within the nectarine crop was probably by hopping from plant to plant at ground level. Numbers of WFT in flight increased inversely with height of sticky trap from the ground. The pale morph was in general always more common than the dark morph of WFT. Numbers of the dark morph were generally higher in the early spring and late fall than at other times of year. The dark morph was sometimes absent on particularly hot days in summer. Males were not present until the emergence of the first generation in May, and were found at an approximate ratio of 4:1 (F:M) throughout the rest of the year. Although WFT showed preferences for different areas over the season, with generally high numbers of WFT in the orchard in the spring, and high numbers in wild land in the fall, there appeared to be no differences in the relative preferences of males and females (dark or pale morph) for location, height of flight or daily patterns of flight.

**KEY WORDS:** *Frankliniella occidentalis*, western flower thrips, diel flight patterns, temperature, morph ratios, sex ratios

## 5.1 INTRODUCTION

The western flower thrips, *Frankliniella occidentalis*, is a serious pest of nectarine orchards in the Dry Central Interior, British Columbia. Larval thrips feeding on the immature buds cause scarring and deformation very early in the life of the fruit (during the blossom to petal-fall stage) which results in unmarketable culls. This damage is currently so extensive that a number of growers are considering removing blocks, and others are deterred from planting. We have carried out a detailed examination of the population dynamics, habitat and biology of this pest from which it is hoped that an appropriate pest management strategy may eventually be created (Pearsall, all chapters). This part of our study examined flight behaviour within and outside of nectarine orchards throughout the growing season. Western flower thrips are highly mobile insects, with both males and females capable of flight (Lewis, 1959). Their patterns of flight behaviour have not been studied to the extent of other insects such as aphids or locusts but, because of their growing economic importance in western Canada and also worldwide, it was deemed appropriate to examine their movement patterns more critically. As outlined by Southwood (1962), thrips are one of the groups of insects often associated with temporary habitats, and thus large scale dispersal from one habitat to another is an important part of their life history. It is also likely that they make a multitude of trivial movements within a location throughout their period of residence, whether these movements are to reach food, shelter or water, to escape natural enemies, or to locate mates and oviposition sites.

Orchards in this region are located primarily on the south-facing lower slopes of narrow, winding valleys named the Similkameen and Okanagan. Wild land which extends over the vast areas of hillside adjacent to the orchards is dominated by sagebrush (*Artemisia tridentata* Nutt.) and rabbitbrush (*Chrysothamnus nauseosus* (Pallas)) and is the primary source of emerging WFT in the spring. The mean direction of dispersal into orchards located adjacent to wild land was found to be primarily from these source areas, regardless

of the dominant wind flow patterns (Pearsall, chapter 4). However, this previous study only considered patterns of movement occurring over periods of several days. In addition, we only looked at flight patterns in the spring and early summer. Here we wished to examine patterns of flight on a diel basis throughout the spring to the late fall/early winter.

Climate, including temperature, wind, relative humidity and atmospheric pressure, is one of the most important factors determining aerial load of insects (Taylor, 1962; Lewis, 1973; Wellington, 1983). At the same time, climatic factors undoubtedly affect the efficiency of certain types of traps, such as sticky traps, designed to measure relative abundance of insects. In this region of British Columbia, Canada, weather patterns can change dramatically over a short period of time due to the terrain. Radiative heating of the ground during the day produces thermal convection and surface turbulence during the day which allow for transport of airborne insects. These thermals may allow thrips to move up to higher levels and become trapped in air currents that are moving at speeds greater than those at which thrips are able to direct their flight.

The western flower thrips has a haplodiploid life-history. Female WFT reproduce by haploid arrhenotoky in which unfertilized, haploid eggs develop into males, and fertilized diploid eggs develop into females. Males are much smaller than females in general, but both sexes are capable of dispersal (Lewis, 1959).

Female WFT are known to exist as three phenotypes: dark, intermediate and pale coloured morphs (Sakimura, 1962). Pergande's original type series for this species contained both light and dark forms, although he actually described *F. occidentalis* as yellow (Pergande, 1895). Because of the variable colouration of this species of thrips, there have been numerous synonyms for this species. One of the earliest synonyms was *F. moultoni*, the name given to the brown colour form of WFT (see also Brodsgaard, 1989a). The dark and pale forms of WFT are homozygous, whereas the intermediate form is heterozygous (Sakimura 1962). Bryan and Smith (1956) discussed the colouration of western flower thrips as follows: the pale form is a white or yellow colour, except for light



brown maculations on the dorsum of the abdomen; the intermediate form has an orange thorax and brown abdomen, and the dark form is completely dark brown. They suggested that the distinctions are not always clear because the pale and dark individuals tend to intergrade with the intermediate forms. Few studies discuss the morph type of WFT when reporting on results of studies of this insect. The dark morphs are generally larger than the pale morphs (Bryan and Smith, 1956). The females are present in two different morphs in the Dry Central Interior: as the pale morph (pale lemon colour) and as the intermediate morph (brown and orange colour). Sometimes WFT were present with both a brown thorax and abdomen, unlike the intermediate morph with the orange abdomen. However, it was very hard to differentiate the two, and thus the two morph types were grouped together as "dark".

I expected the differences of size among male and female WFT, and in the size of the two different female colour morphs, to be associated with differences in the flight behaviour of the three groups. Thus I wished to examine whether the dark morph is able to take off, and is found flying earlier than the pale morph female because of thermodynamic effects, and whether the pale morph can withstand higher temperatures and be present in the air stream on hotter days. I also expected that males would show more erratic flight patterns: being so small and light, they may have little control of flight direction or height, and be more easily carried in thermal updrafts. I also wished to examine whether males are present in the air column when conditions are absolutely calm: they may need movement of air to take flight.

It is likely that thrips within orchards do not engage in trivial flight unless conditions are favourable. However, when this habitat is no longer suitable, that is, when the trees are no longer in bloom, thrips are likely to migrate out of the orchards to new temporary habitats. This study was carried out in three habitats: within nectarine orchards, at the orchard edge (where a variety of different weed and wild flower species are present) and within wild land (where sagebrush is the dominant vegetation). The study was begun

in early spring as thrips migrate from sagebrush into orchards during nectarine bloom and ended in late fall when thrips had left the orchards and moved back into the wild land during which period the sagebrush is in bloom (Pearsall, pers. obs.). Flight behaviour was studied on thirteen occasions between March and October in two different orchards which are located on the sides of the Similkameen valley and are flanked on one side by large sections of wild land.

The study of flight behaviour was concerned with diel patterns of local flight and was carried out in order to answer several basic questions:

- 1) What are the threshold temperatures (upper and lower) for initiation and cessation of flight?
- 2) Is there a upper threshold for wind speed which may prevent flight?
- 3) Is there a relationship between height of flight and temperature?
- 4) Is there a relationship between height of flight and vegetation structure in the surrounding area (wild land, orchard edge and within orchard)?
- 5) Do patterns of flight vary among the three different locations, orchard, edge and wild land?
- 6) What is the diel pattern of flight within each orchard and does it vary with time of year and daily changes in temperature? What is the diel pattern of wind direction in the valley and does there appear to be any characteristic flight response associated with it?
- 7) Do the dark and pale morphs of WFT show any differences in flight behaviour? Do male and female WFT show any differences in their flight behaviour? Are there any differences in height of flight, response to temperature and wind speed, or differences in location preference?

## 5.2 MATERIALS AND METHODS

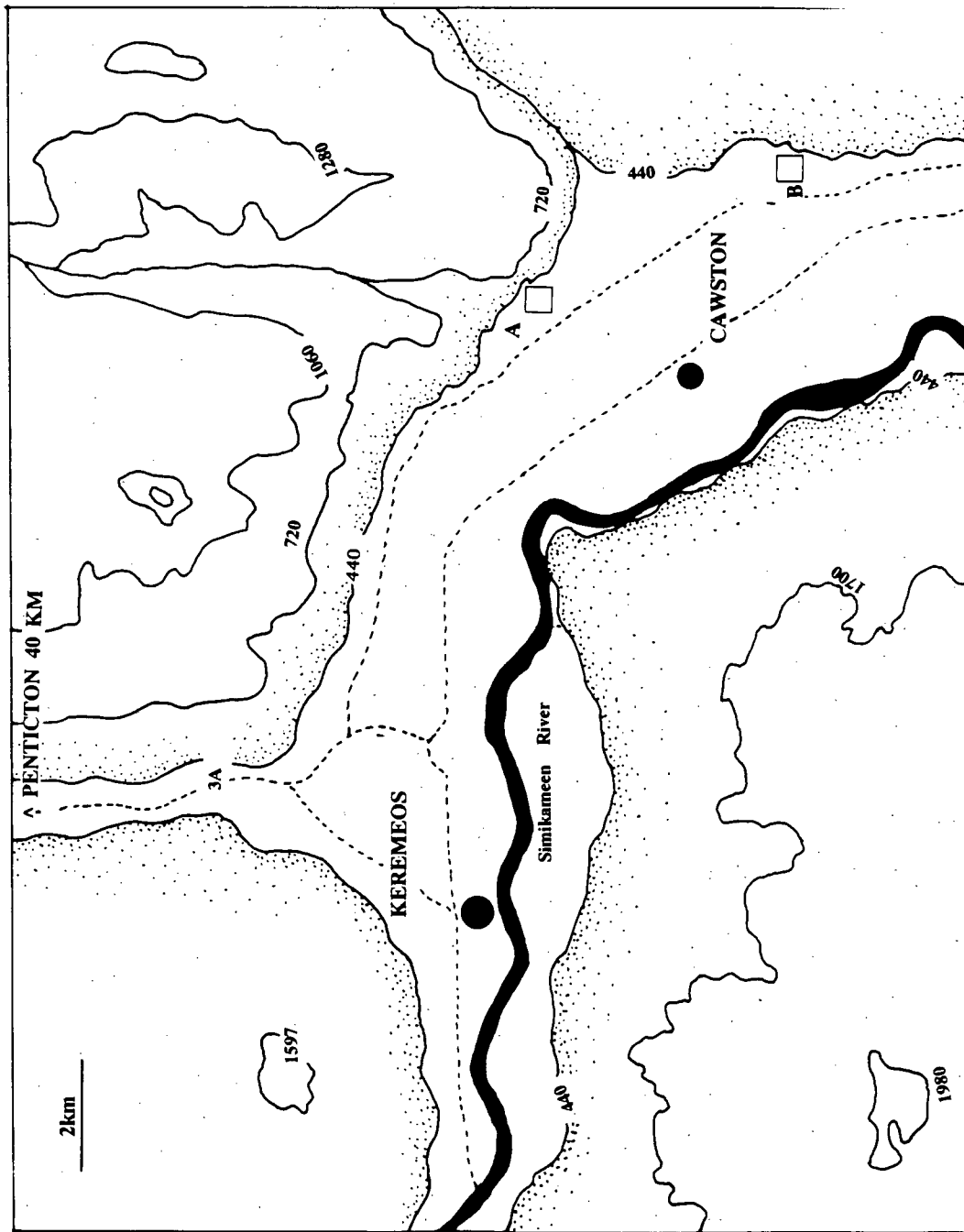
### Study sites

Western flower thrips (WFT) were sampled hourly from two orchards, A and B (Figure 5.1). Orchards A and B are located in the Similkameen valley, in the interior of British Columbia. The two orchards are very similar in terms of aspect, climate, wind patterns and varieties of nectarine fruit grown: both orchards lie on the south-facing slope of the valley, at approximately 400 feet above sea level, adjacent to vast tracts of wild lands. The predominant variety of nectarine grown in both orchards is "Redgold".

### Methods

Seven two-metre-high posts were set up in each orchard with three posts located within the orchard, two at the orchard edge and two within an adjacent area of wild land. Counts were made over a period of 24 hours on 13 separate occasions between late dormancy (March 31) and post fruit harvest (October 9) in 1994. Sticky cards were set up at four to eight heights on each post and the number of western flower thrips (male, female, and numbers of each of the pale and dark morphs) caught per hour were recorded. Early in the spring, counts were made at eight heights (0.25, 0.5, 0.75, 1.0, 1.25, 1.5, 1.75 and 2 m) but as densities of thrips increased, the number of cards per post was reduced lest these should provide too great a stimulus to thrips and therefore obscure natural flight heights. Thus for dates between 30 May and 9 October, counts were made from only four heights (0.25, 0.75, 1.25, and 1.75 m). This study was carried out on the following dates: 31 March (Orchard B only); 3 April (A & B); 4 April (A & B); 13 April (B only); 17 April (B only); 19 May (A & B); 30 May (A & B); 13 June (A & B); 27 June (A & B); 11 July (A & B); 24 July (A & B); 19 August (A & B); 9 October (A & B).

Yellow sticky cards (7.5 cm by 13 cm) were used in this study as the visibility of WFT on cards of this colour was found to be superior to that on blue cards, and ease and



**Figure 5.1** Diagram of the location of orchards A and B in the Similkameen Valley in the interior of British Columbia, Canada.

rapidity of counting were paramount to the feasibility of this study. In addition, according to Matteson and Terry (1992), yellow sticky traps do not differentially attract either sex. Cards were set up at 0700 and counts were made every hour until it was dark ca. 1800-2100. WFT were counted on site. When densities were low, the WFT were dotted using a permanent marker (black colour) on the card so that they were not counted again one hour later. When densities on a card were high, the count was made, and the card immediately replaced. Location A counts were carried out on every half-hour, those of location B on the hour. Clearly, the counts could not all be made exactly on the hour or half-hour, but generally within 20 minutes. A final count was made the following morning at 0700. In addition, hourly records were made of the temperature, the wind direction, wind speed and general weather conditions. Hourly wind speed was taken at all heights using a hand held anemometer. Hourly temperature was recorded in both orchards and areas of wild land at both ground level (0.25 m) and at mid canopy level (1.25 m).

For the sake of clarity, the seven posts within and around orchard A are part of "location A" whereas the posts in and around orchard B belong to "location B". "Edge", "wild" and "orchard" are referred to as "areas".

### **Data analysis**

The relationship between hourly temperature and height of flight over all twelve days was examined using simple linear regression.

### 5.3 RESULTS

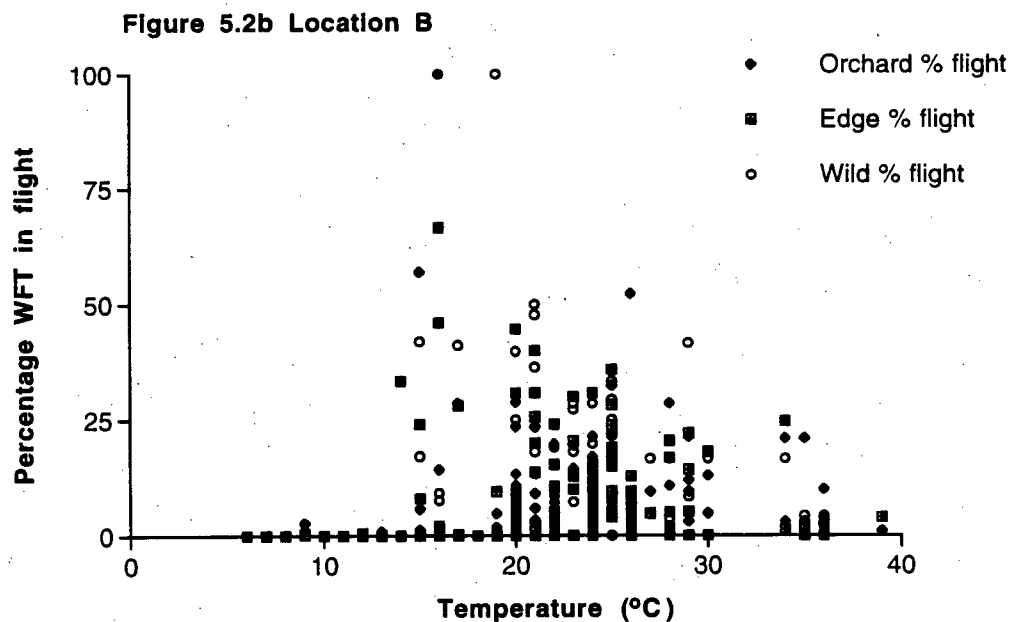
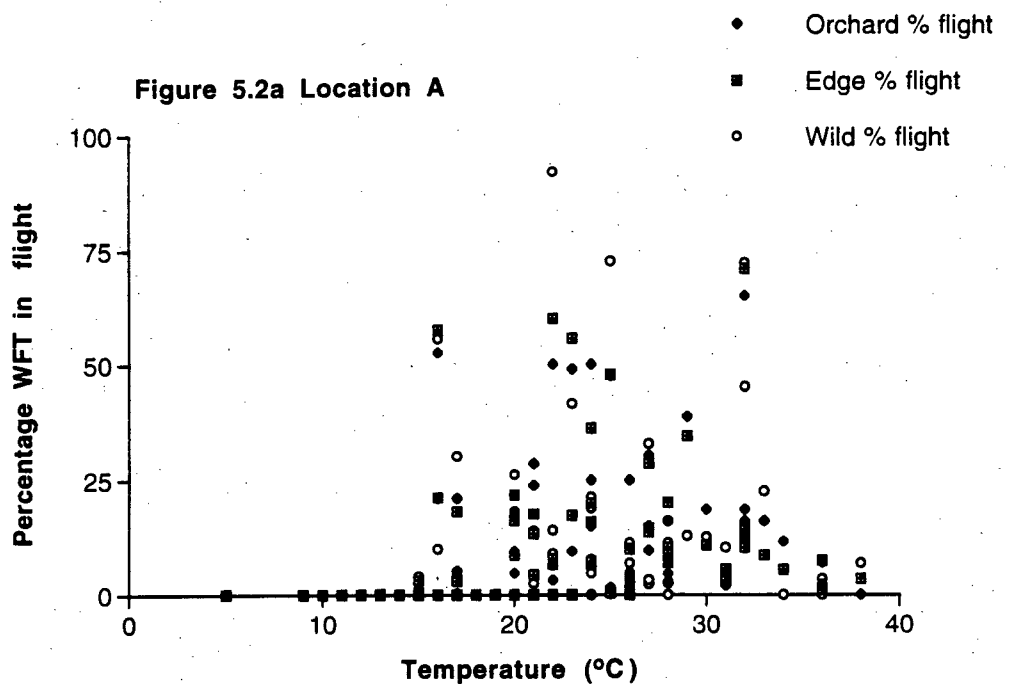
No flight occurred on 4 April and thus this day is omitted from all graphs except for Figures 5.2 - 5.4 in which we examined temperature and wind thresholds.

#### 1) *Threshold temperatures (upper and lower) for initiation and cessation of flight.*

We examined the relationship between flight and temperature for each orchard by expressing the numbers of WFT in flight every hour on a particular post as a ratio of the total numbers of WFT caught over the whole day on that post, and plotting this against the hourly air temperature. For this part of our study, we interpreted the term "in flight" to be those WFT caught on or above cards placed at a height of 75 cm only. It is possible that below this height, thrips may be able to simply 'hop' onto cards from the surrounding ground cover (which varied between 5 cm and 50 cm above ground level) regardless of temperature or wind speeds and thus catches on cards below this level may not be a true indication of flight. Flight did not occur to any great extent in either orchard at temperatures below 15°C, and the ideal range appeared to be between 17 and 29°C (Figures 5.2a,b). Flight was reduced at temperatures above 30°C and minimal at temperatures above 35°C (Figures 5.2a,b).

#### 2) *Wind speed threshold.*

We examined the effect of wind speed on flight by plotting the number of thrips flying at any particular height each hour divided by the total daily flight occurring at that height against the prevalent wind speed for that hour. The proportions of total daily flight were calculated for each location A and B and for orchard, edge and wild separately, and only for those hours when temperature was within the ideal temperature range (17-30°C). There was a clear effect of high wind speed on flight (Figures 5.3a-h (A), 5.4a-h (B)). Note that there are fewer data points for the heights 0.5, 1.0, 1.5, and 2 m since these heights were only sampled on the first five days of the study. Flight was greatly reduced at



**Figure 5.2a,b** Relationship between temperature and % flight as assessed from catches on sticky cards in a) location A and b) location B in 1994. The % flight is expressed as the no. WFT in flight on any particular post each hour as a ratio of the total numbers of WFT caught over the whole day at that post for all heights above 75 cm.

Figure 5.3a Location A- 25cm

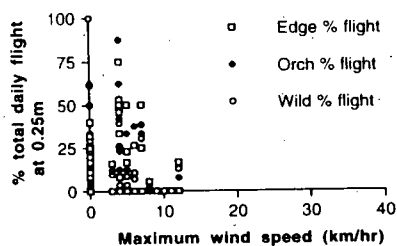


Figure 5.3b Location A- 50cm

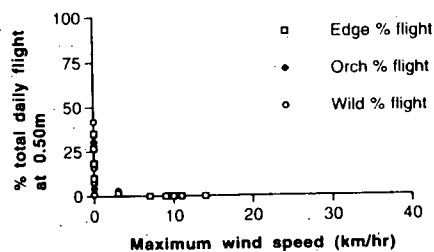


Figure 5.3c Location A- 75cm

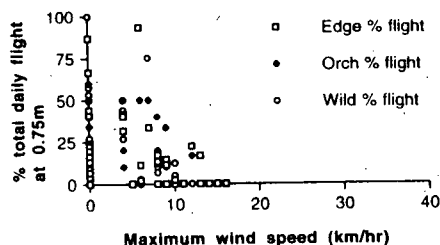


Figure 5.3d Location A- 1.00m

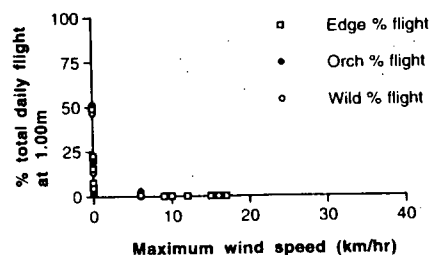


Figure 5.3e Location A-1.25m

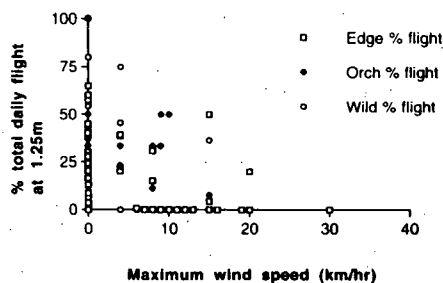


Figure 5.3f Location A-1.50m

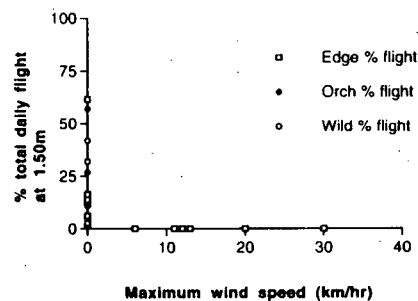


Figure 5.3g Location A- 1.75m

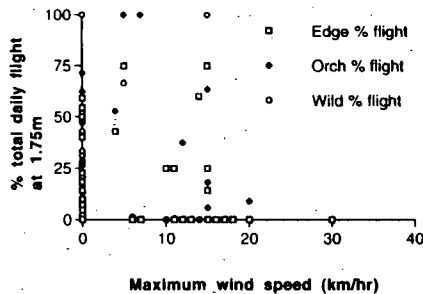
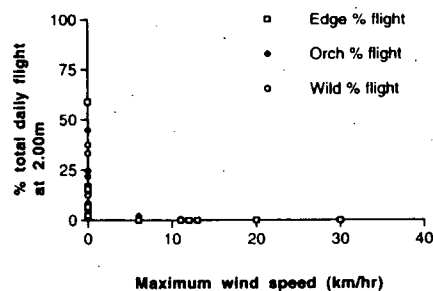
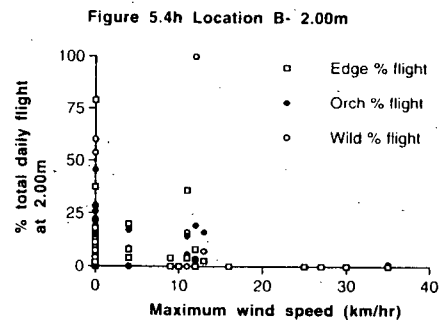
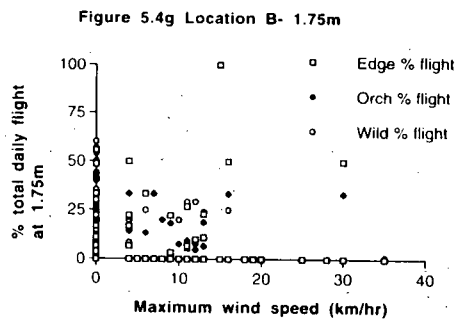
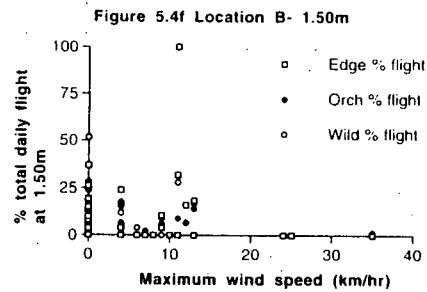
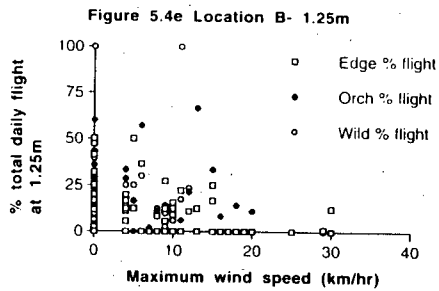
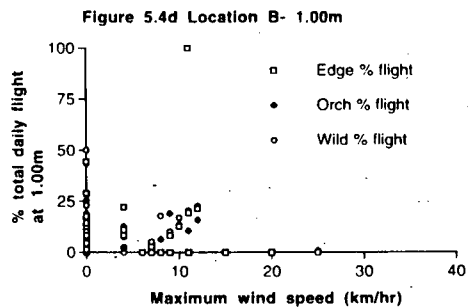
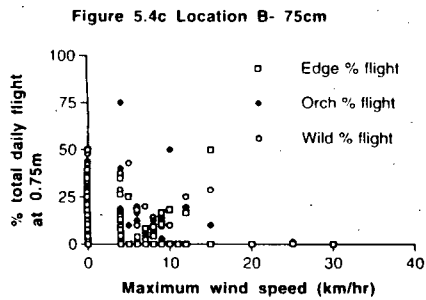
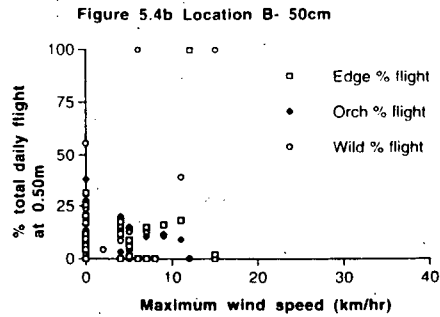
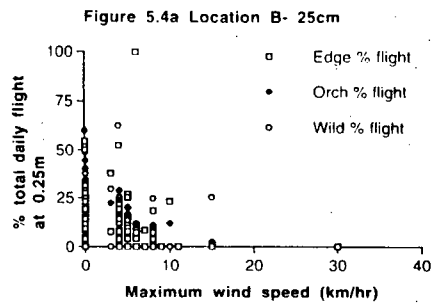


Figure 5.3h Location A-2.00m



**Figure 5.3a-h** Relationship between the percentage of total daily flight occurring at a) 0.25 m, b) 0.5 m, c) 0.75 m, d) 1.00 m, e) 1.25 m, f) 1.5 m, g) 1.75 m and h) 2.00 m and the maximum wind speed (km per hour) for location A.





**Figure 5.4a-h** Relationship between the percentage of total daily flight occurring at a) 0.25 m, b) 0.5 m, c) 0.75 m, d) 1.00 m, e) 1.25 m, f) 1.5 m, g) 1.75 m and h) 2.00 m and the maximum wind speed (km per hour) for location B.

wind speeds above 15 km/hour. However, the effect of wind speed on flight appeared to depend upon the height at which flight was occurring. At higher levels, (1.25 m and higher), thrips were caught at higher wind speeds than at the lower level sticky cards, with thrips caught at wind speeds as high as 20 km/hour for location A, and as high as 30 km/hour in location B (Figures 5.3g, 5.4g).

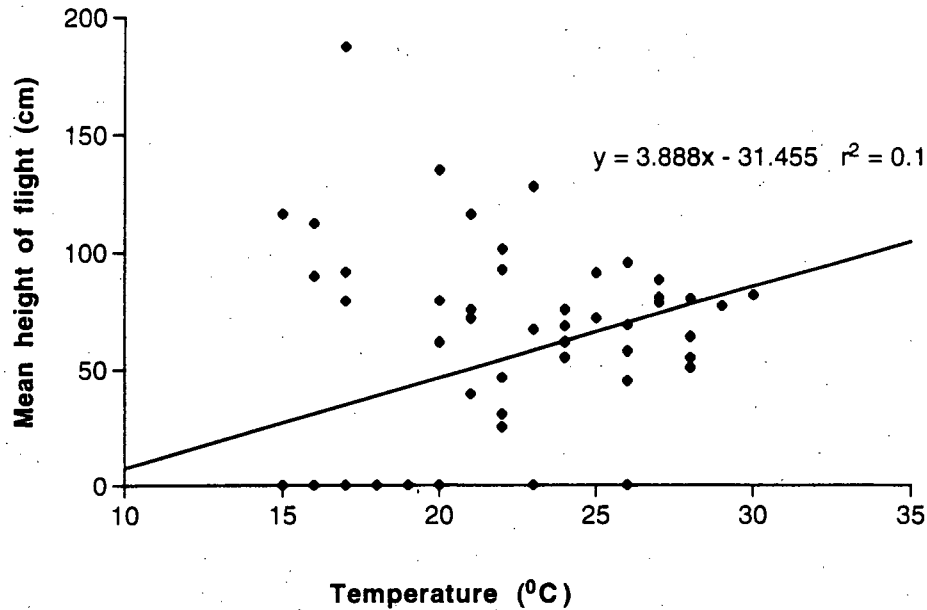
### 3) *Height of flight and temperature.*

Mean height of flight per post per hour for each location (orchard, edge and wild posts combined) was plotted against the hourly air temperature (as measured at 1.25 m above the ground for all twelve dates of study). We only plotted the mean height for those hours during which both temperature and wind speeds were within the ideal range (15-30°C for temperature and winds below 15 km per hour.) Mean height of flight of WFT showed a positive relationship with hourly temperature in both locations (linear regression, Orchard A:  $\log(x+1)$  transformed data:  $F=33.64$ ,  $df=1,61$ ,  $P=0.000$ , Orchard B:  $\log(x+1)$  transformed data:  $F=31.87$ ,  $df=1,118$ ,  $P=0.000$ ). Figures shown are for untransformed data (Figures 5.5a,b).

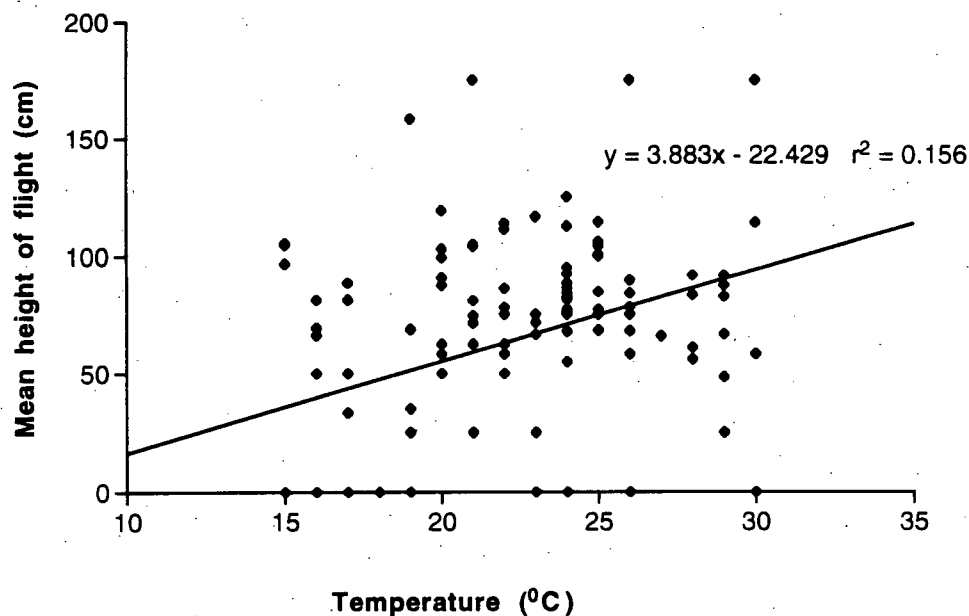
### 4) *Height of flight and vegetation structure in the surrounding area.*

We examined modal height per day rather than the mean as we were interested in relating the height at which most thrips are flying with the modal height of the surrounding vegetation. In the case of wild land, most of the vegetation (top of the sagebrush canopy) was approximately 75 cm from the ground. At the orchard edge, height of vegetation was approximately 75 cm-1 m, including primarily sagebrush (*Artemisia tridentata* Nutt.), black mustard (*Brassica nigra* (L.)), white sweet clover (*Melilotus alba* Medikus) and yellow sweet clover (*Melilotus officinalis* (L.)). Within the orchards themselves, vegetation consisted of nectarine trees and flowering ground cover: mainly red clover (*Trifolium*

**Figure 5.5a Location A**



**Figure 5.5b Location B**



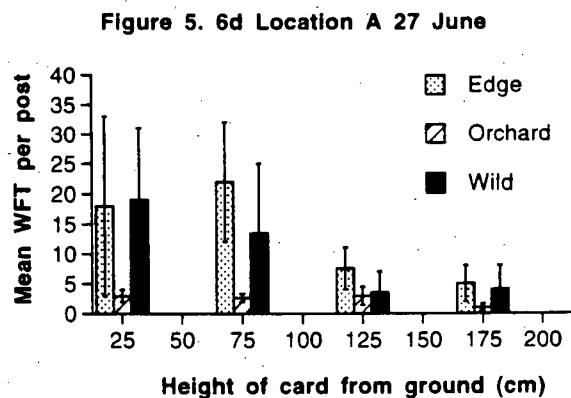
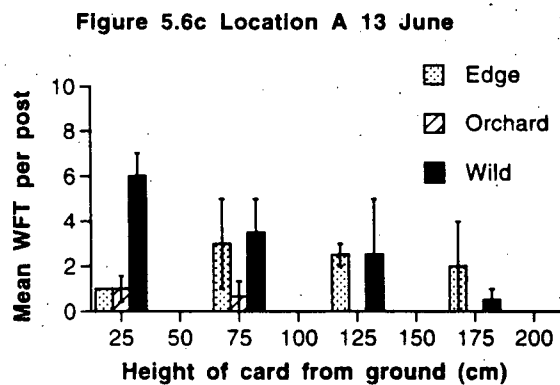
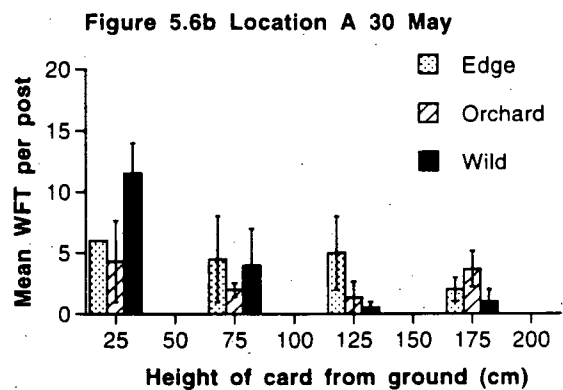
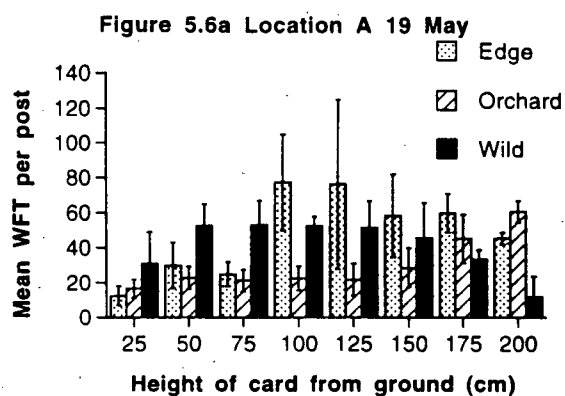
**Figure 5.5a,b** Relationship between the mean height of flight (cm) and the air temperature (°C) (measured at 1.25 m above ground) as described using linear regression for a) Location A (orchard, edge and wild combined) and b) Location B (orchard, edge and wild combined) for those hours where both wind speed and temperature are in the ideal range for flight (<15km/hour winds and temperatures between 15-30°C).

*pratense* L.), white clover (*Trifolium repens* L.), dandelions (*Taraxacum officinale* Weber), hairy vetch (*Vicia villosa* Roth), black mustard (*Brassica nigra* (L.)), and alfalfa (*Medicago sativa* L.) at a modal height of 25-50 cm above ground.

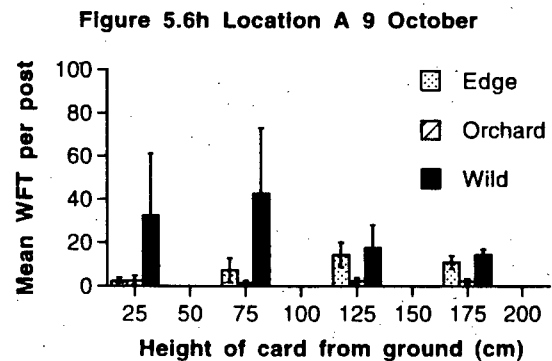
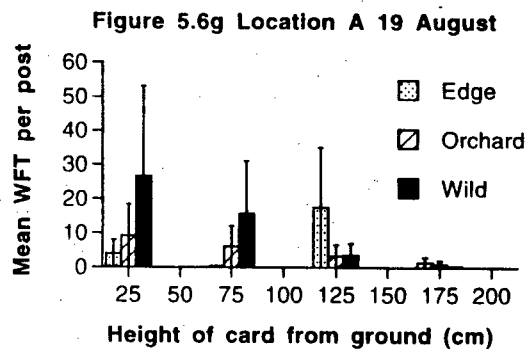
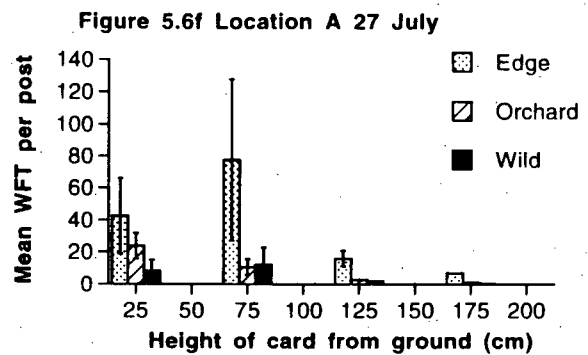
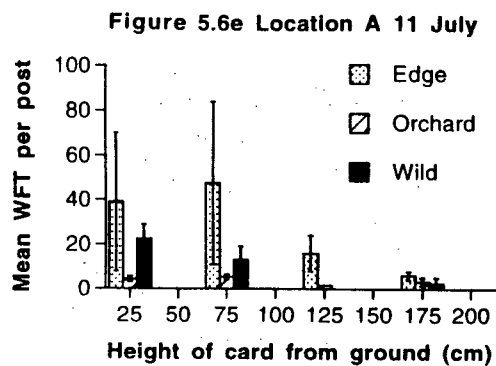
Ground cover blooms were present from April onwards, although these were sometimes reduced in density after mowing. Throughout the period of nectarine bud development, there was a strong stimulus between 1 and 2 m above the ground in the form of these pink buds/blooms. The miniature fruit, when present, were fairly inconspicuous within the tree canopy until the fruit began to turn red (Table 5.1).

In location A, the first sample date on which flight occurred coincided with the emergence of the first generation (19 May), when there was no bloom left on the trees. Trees in this orchard were approximately 2 m tall, and the canopy itself extended from between 1 and 2 m. On 19 May, flight was fairly even at all heights (Table 5.2, Figure 5.6a). For the rest of the sampling occasions, most flight generally occurred at ground level for both orchard and wild locations, although at the orchard edge, most flight occurred at 75 cm (Table 5.2, Figures 5.6b-h). The dominant vegetation at the orchard edge was sweet white clover, which grew to approximately 75 cm to 1 m in height.

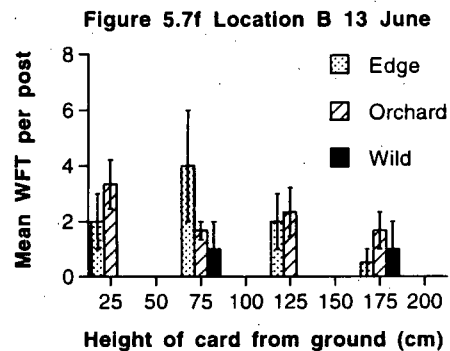
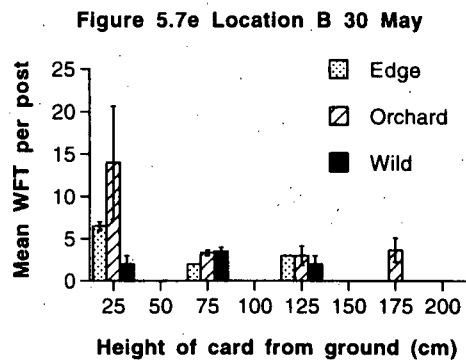
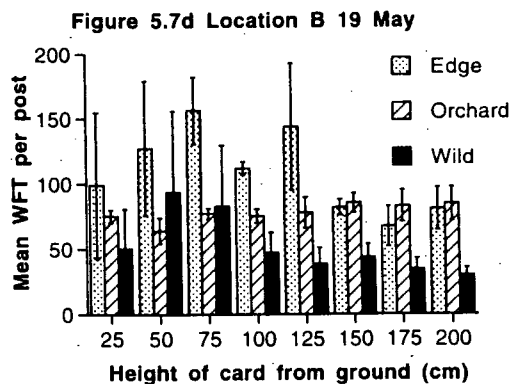
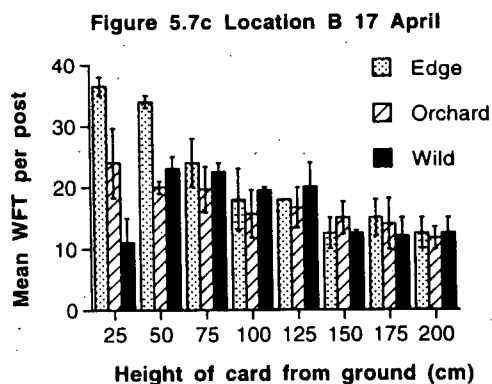
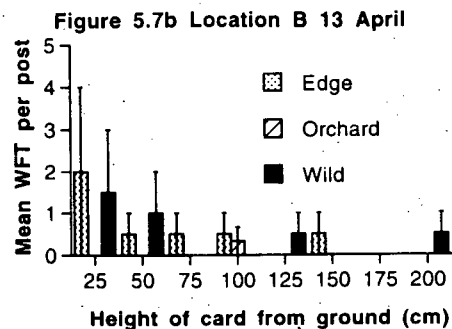
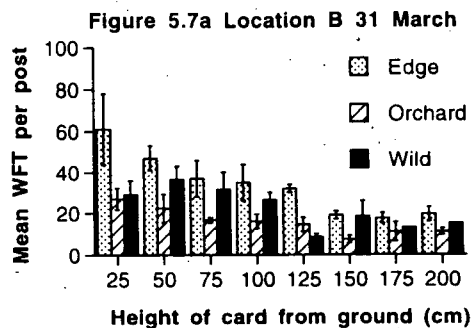
In location B, on most dates, the majority of thrips in flight in wild land were caught at the 50-75 cm heights, which is the mean height of the surrounding vegetation (primarily sagebrush), and at 25-75 cm at the orchard edge, which reflected the different heights of wild flowers and weeds at this location as they bloomed at different dates (Table 5.2, Figures 5.7a-k). Within the orchard, height of flight was more variable and tended to change over the season with changes in the vegetation structure within orchards (Tables 5.1, 5.2, Figures 5.7a-k). In general, most flight was at the 25 cm level, particularly in orchard B which has a dense mat of dandelions and other flowering ground cover. The particular days that these trials were carried out during the flowering periods in the two orchards were either unusually cool or windy such that there were very low numbers of western flower thrips in flight. However, prior studies have shown that the numbers of



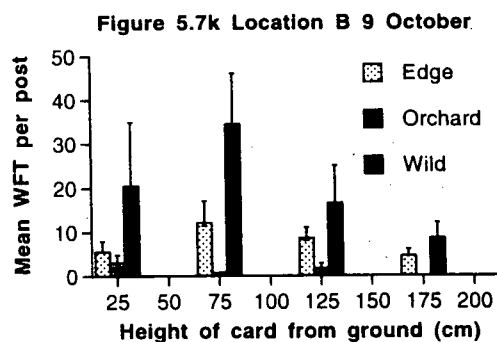
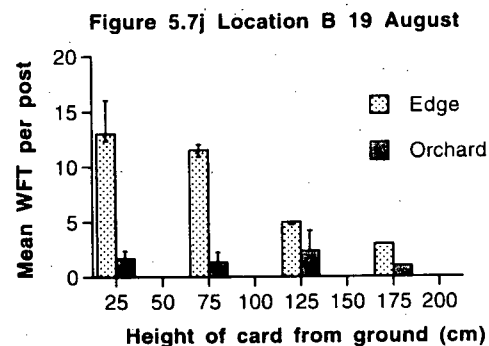
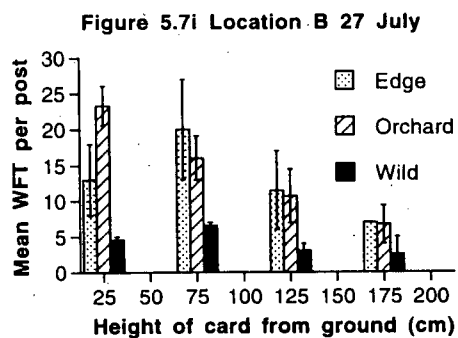
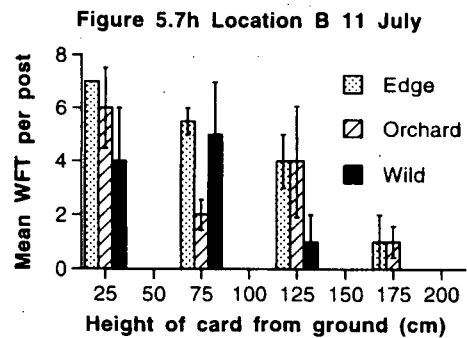
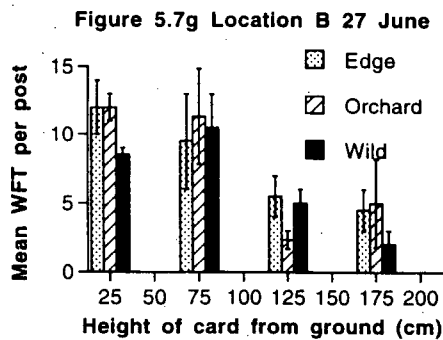
**Figure 5.6a-d** Diagrams showing the number of WFT caught at each of the 4-8 different heights (at 0.25, 0.50, 0.75, 1.00, 1.25, 1.50, 1.75, & 2.00 m on 19 May and at 0.25, 0.75, 1.25, 1.75 m after 19 May) for each sample date from 19 May - 27 June in location A.



**Figure 5.6e-h** Diagrams showing the number of WFT caught at each of four different heights (0.25, 0.75, 1.25, 1.75 m) for each sample date from 11 July - 9 October in location A.



**Figure 5.7a-f** Diagrams showing the number of WFT caught at each of the 8 different heights (at 0.25, 0.50, 0.75, 1.00, 1.25, 1.50, 1.75, & 2.00 m prior to and on 19 May and at 0.25, 0.75, 1.25, 1.75 m after 19 May) for each sample date from 31 March - 13 June in location B. Data from 3 April is not included as there was so little flight on this date.



**Figure 5.7g-k** Diagrams showing the number of WFT caught at each of four different heights (0.25, 0.75, 1.25, 1.75 m) for each sample date from 24 June - 9 October in location B.



WFT in flight during this period increases at the level of the tree canopy (75-150 cm dependent upon the size of trees in an orchard) (Pearsall, chapter 4). On 17 April and 19 May, the conditions were very warm, there were many flowers blooming in the ground cover, many new leaves on the trees and on the latter date, the densities of WFT were particularly high as emergence of the new generation was occurring at this time. There were still flowers present on the trees on 17 April, and thus flowers were present at both ground level and throughout the canopy (~1-2 m above ground) for that date. Flight on both these days was generally similar at all heights. On August 19, when fruit in orchard B was bright red and about to be harvested, the height of flight was greatest at the 125 cm level, coincident with this stimulus at the canopy level.

**Table 5.1** Stage of bloom and condition of ground cover in orchards A and B on the 13 sample dates. The sample day is in parentheses.

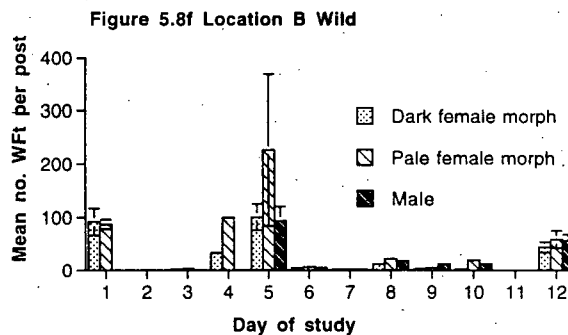
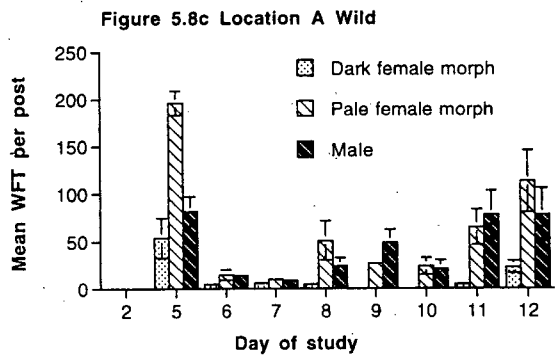
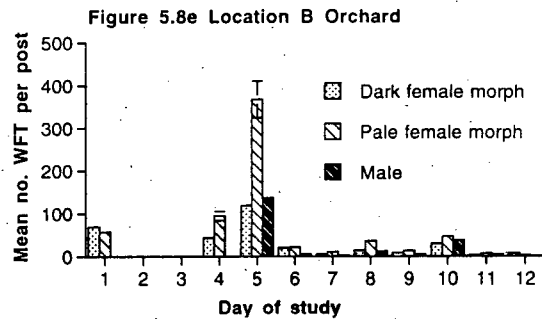
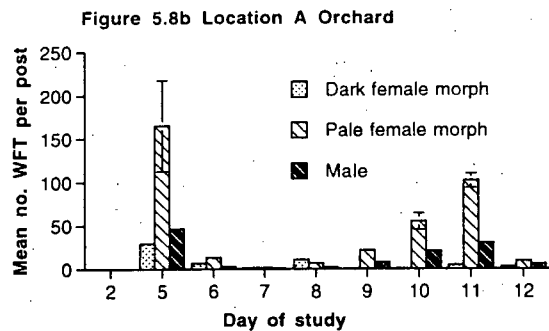
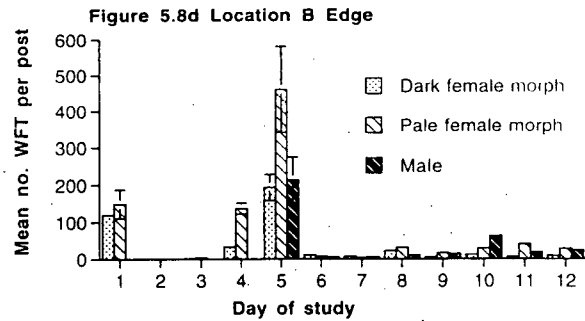
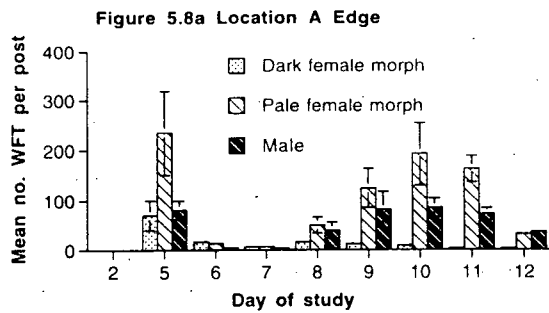
| <b>Date (Day)</b>     | <b>State of bloom in orchard</b>  | <b>Ground cover in orchard</b>                                     |
|-----------------------|---|--|
| <b>March 31 (1)</b>   | B= petal show and some white swell buds   | Grass only   |
| <b>April 3 (2)</b>    | A= bloom, B= Pink   | A= Dandelions beginning to bloom                                   |
| <b>April 4</b>        | A= bloom, B= 5% Pink  | Dandelions blooming  |
| <b>April 13 (3)</b>   | B= full bloom/late bloom  | B=Dandelions dense   |
| <b>April 17 (4)</b>   | B= 25% petal fall and late bloom  | Dandelions blooming, dense in B                                    |
| <b>May 19 (5)</b>     | Fruit on trees (about 1-4 cm long in both orchards)   | B= recently mown, few blooms in both orchards                      |
| <b>May 30 (6)</b>     | Fruit in A & B, (hay & alfalfa field adjacent to orchard B cut the week prior to sampling). | red and white clover, few dandelions, A= recently mown             |
| <b>June 13 (7)</b>    | Fruit in A & B  | sparse dandelion, clover and black mustard in both orchards        |
| <b>June 27 (8)</b>    | Fruit in A & B  | both orchards recently mown  |
| <b>July 11 (9)</b>    | Fruit in A & B. Fruit green and about 3-5 cm long in both orchards.                         | abundant clover, mustard, purple alfalfa                           |
| <b>July 24 (10)</b>   | Fruit in A & B, red in A, green in B. Fruit about 6 cm long.                                | clover, dandelions (few) and mustard in B, orchard A recently mown |
| <b>August 19 (11)</b> | Fruit just prior to harvest in A & B  | sparse ground cover, B mown  |
| <b>October 9 (12)</b> | Post harvest in A & B   | ground cover flowering, sagebrush at bloom/late bloom              |

**Table 5.2** Modal height (cm) of flight for each sampling occasion. NF= no flight was recorded, E = flight was even at all levels. N= total number of thrips counted. Between 31 March and 19 May sticky cards were placed at eight heights (0.25, 0.50, 0.75, 1.00, 1.25, 1.50, 1.75 and 2.00 m). From May 30 onwards, sticky cards were only placed at four heights (0.25, 0.75, 1.25 and 1.75 m).

| Date    | Location A |      |      |       | Location B |       |       |       |
|---------|------------|------|------|-------|------------|-------|-------|-------|
|         | Orch       | Edge | Wild | N     | Orch       | Edge  | Wild  | N     |
| Mar 31  |            |      |      |       | 25         | 25    | 50    | 9880  |
| Apr 3   | NF         | NF   | NF   | 0     | NF         | NF    | 50    | 4     |
| Apr 13  |            |      |      |       | NF         | 25    | 25    | 107   |
| Apr 17  |            |      |      |       | 25 (E)     | 25(E) | 50(E) | 8136  |
| May 19  | E          | E    | 75   | 17240 | E          | 75    | 50    | 35274 |
| May 30  | 25         | 25   | 25   | 388   | 25         | 25    | 75    | 413   |
| June 13 | 25         | 75   | 25   | 186   | 25         | 75    | 75    | 190   |
| June 27 | 25         | 75   | 25   | 664   | 25         | 25    | 75    | 828   |
| July 11 | 75         | 75   | 25   | 880   | 25         | 25    | 75    | 353   |
| July 24 | 25         | 75   | 75   | 220   | 25         | 75    | 75    | 672   |
| Aug 19  | 25         | 125  | 25   | 1668  | 125        | 25    | NF    | 333   |
| Oct 9   | 25         | E    | 75   | 1311  | 25         | 75    | 75    | 948   |

##### 5) Variation of flight among orchard, edge and wild land.

The patterns of flight on posts located within wild land, orchard edge, and within the orchards showed fairly good synchrony among areas at least in location B (Figures 5.8d-f). The densities of thrips per card within wild land and orchard edge areas were higher than within the orchard itself in early March at the time of thrips emergence from their overwintering sites, which appear to be located to a great extent within wild land (Pearsall, chapter 2). Densities were high in all three areas, although slightly higher at the orchard edge during the second main peak on 19 May, which occurs when the new



**Figure 5.8a-f** Numbers of WFT (dark and pale morph females and males) caught per post (eight cards prior to and on 19 May, four cards after 19 May) for each sample date in a) edge, b) orchard and c) wild areas of location A and d) edge, e) orchard, and f) wild areas of location B.

generation of adult WFT emerge. Throughout the rest of summer, density of WFT was generally low. Numbers of WFT at that time were generally higher within the orchard and at the orchard edge than in wild land. Higher numbers within the orchard were probably the result of irrigation, which occurred on a daily or bi-daily basis and kept the ground cover within orchards flowering and thus attractive to WFT. This was no doubt especially important later in the summer when this valley became extremely desiccated. Higher numbers at the orchard edge was probably the effect of the large numbers of weeds and wildflowers which were found to be more concentrated at the orchard edge than in wild land. Densities of WFT were generally low from June to August when temperatures were particularly high, after which time WFT were more common in wild land, presumably due to the attraction of the rabbitbrush and sagebrush blooms which occur in September and October. Patterns were different in location A, where densities were generally much higher on cards located at the orchard edge and in wild land than on posts within the orchard itself (Figures 5.8a-c). However, the emergence peak on 19 May in all locations, and October peak of WFT in wild land, as were seen in orchard B, also were apparent in this orchard. The emergence peak was generally lower in density in orchard A than B, but densities of WFT at the edge of orchard A throughout the summer were generally much higher than the densities of WFT in and around orchard B.

6) *Variation in the diel pattern of flight with time of year, daily changes in temperature and wind direction in the valley.*

Western flower thrips flew only during daylight hours. All cards placed out in orchards at night before each separate day of study (1900-2200 depending on time of year) and collected at 0600-0700 the following morning yielded no thrips. The only day of study in which there was a non-zero catch on the first hourly count was the first day of study, 31 March. I set the cards up approximately 1800 the evening before, and, it is most likely that

Dark morph female WFT —□— Pale morph female WFT —○—  
 Temperature at 1.25m —○— Av. Wind Speed at 1.25m —□—  
 Av. Wind Speed at 0.25m —●—

Figure 5.9a Location B 31 March

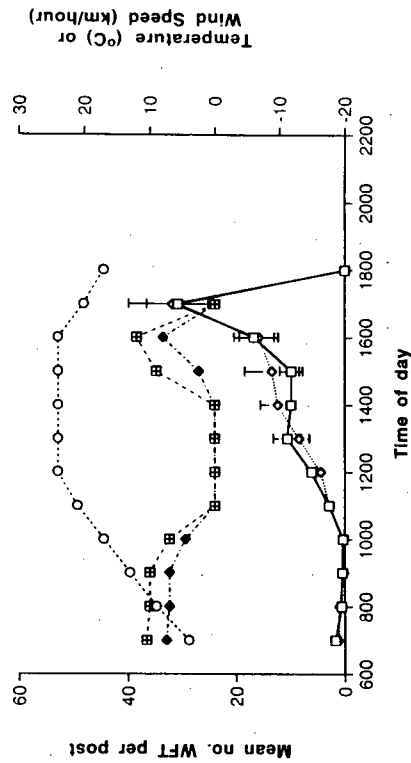


Figure 5.9b Location B 3 April

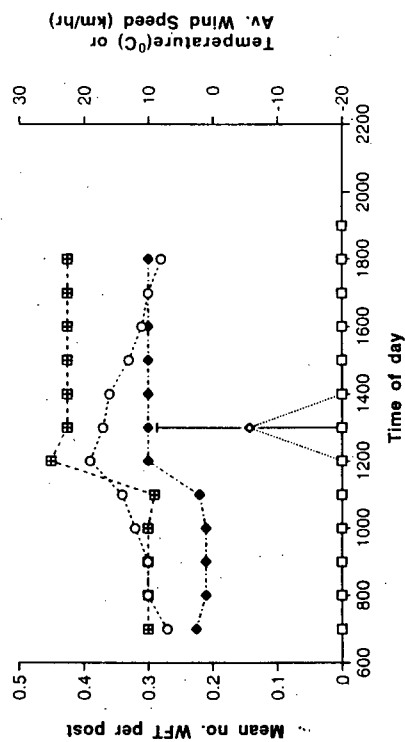


Figure 5.9c Location B 13 April

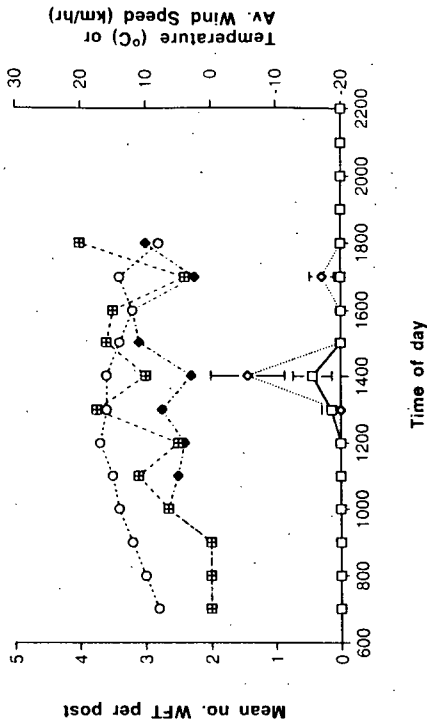
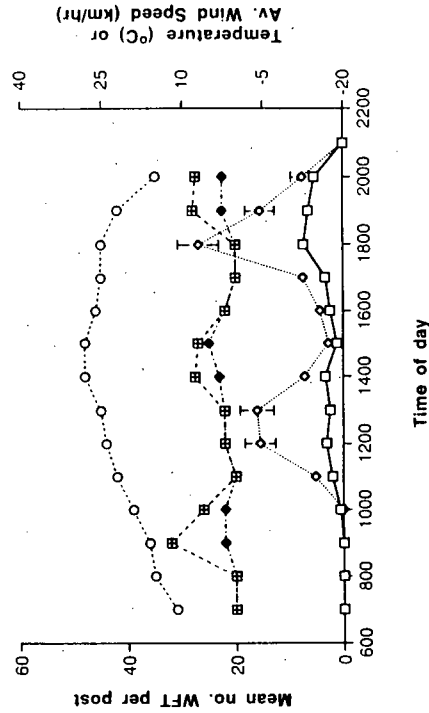


Figure 5.9d Location B 17 April



**Figure 5.9a-d** Hourly patterns of flight in location B for each sample date between 31 March and 17 April. Mean number of WFT per post (from orchard, edge and wild areas combined) are plotted against the temperature at 1.25 m ( $^{\circ}\text{C}$ ) and at 0.25 m (when different to that at 1.25 m) and the average wind speed at 0.25 m and 1.25 m.

Dark morph female —□— Pale morph female  
 Male —○— Temperature at 1.25m  
 Av. Wind Speed at 1.25m —●— Av. Wind Speed at 0.25m

Figure 5.9e Location A 19 May

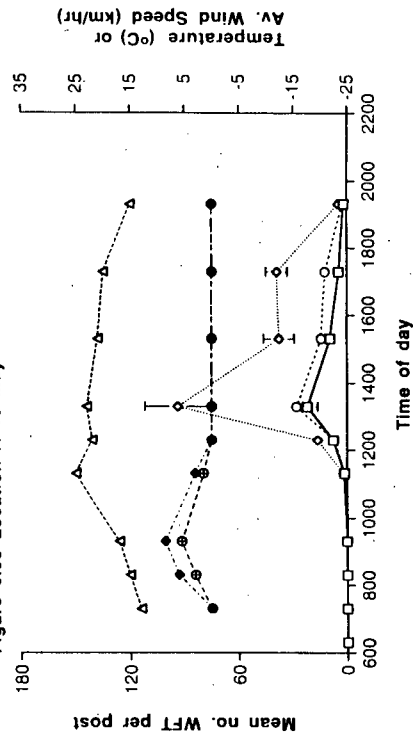


Figure 5.9g Location A 30 May

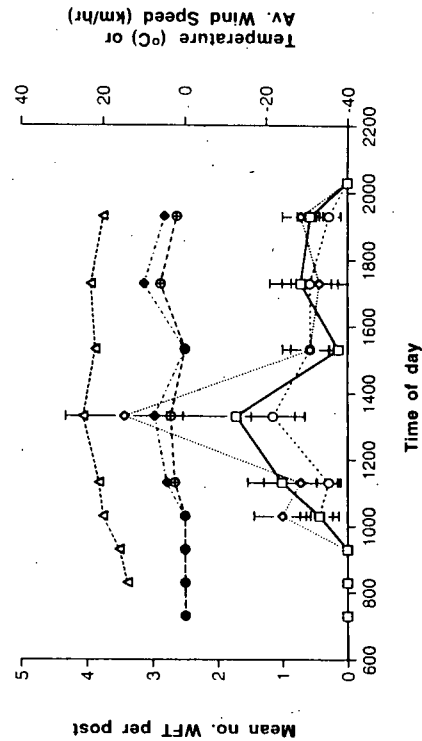


Figure 5.9f Location B 19 May

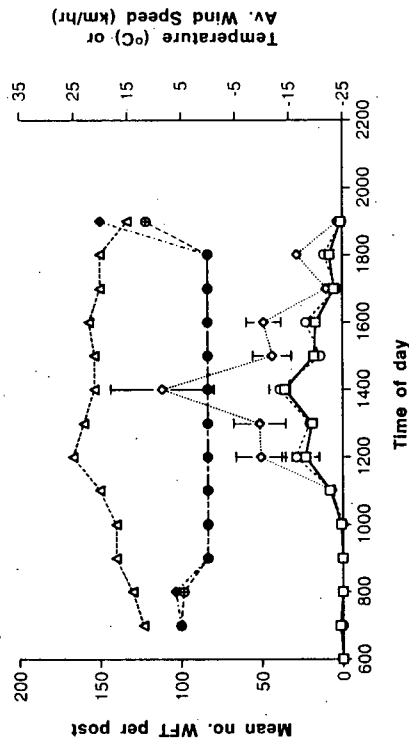
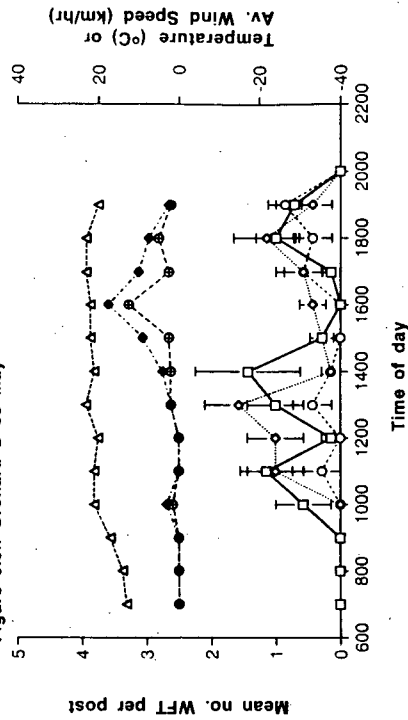


Figure 5.9h Orchard B 30 May



**Figure 5.9e-h** Hourly patterns of flight in locations A and B for 19 and 30 May. Mean number of WFT per post (from orchard, edge and wild areas combined) are plotted against the temperature at 1.25 m (°C) and at 0.25 m (when different to that at 1.25 m) and the average wind speed at 0.25 m and 1.25 m.

Dark morph female —□— Pale morph female  
 Male —○— Temperature at 1.25m  
 Av. Wind Speed at 1.25m —●— Av. Wind Speed at 0.25m —△—

Figure 5.9i Location A 13 June

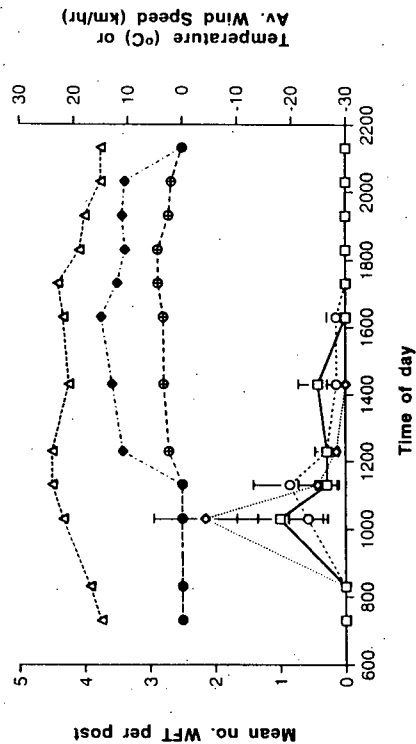


Figure 5.9j Location B 13 June

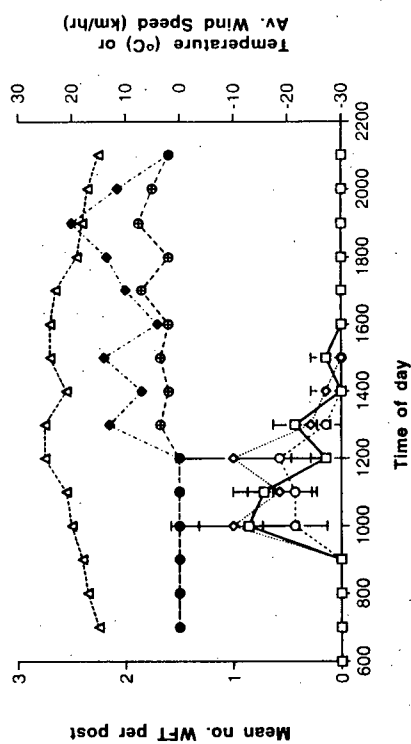


Figure 5.9k Location A 27 June

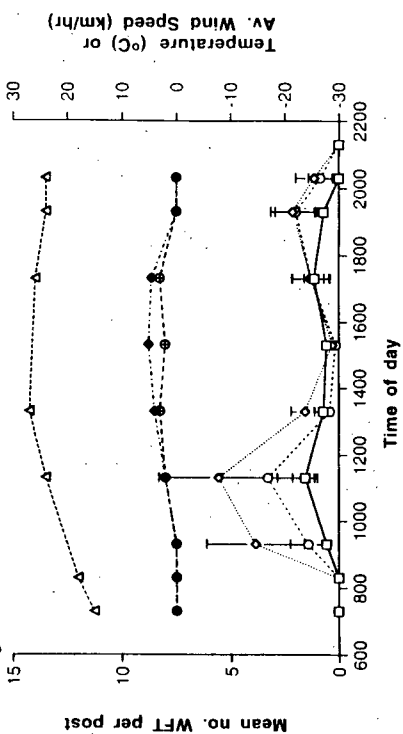


Figure 5.9l Location B 27 June

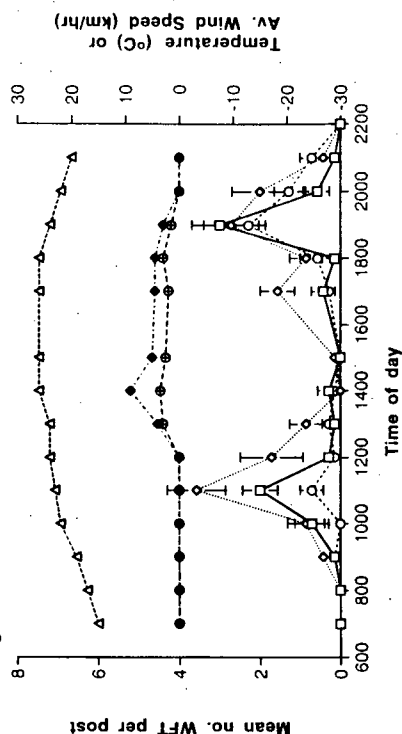


Figure 5.9i-l Hourly patterns of flight in locations A and B for 13 and 27 June. Mean number of WFT per post (from orchard edge and wild areas combined) are plotted against the temperature at 1.25 m (°C) and at 0.25 m (when different to that at 1.25 m) and the average wind speed at 0.25 m and 1.25 m.



Dark morph female —□—  
 Male —○—  
 Temperature at 0.25m —△—  
 Temperature at 1.25m —◇—  
 Av. Wind Speed at 0.25m —■—  
 Av. Wind Speed at 1.25m —●—

Figure 5.9m Location A 11 July

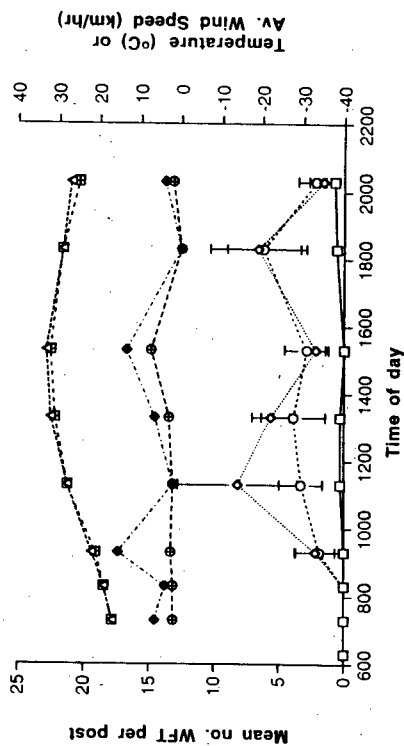


Figure 5.9o Location A 24 July

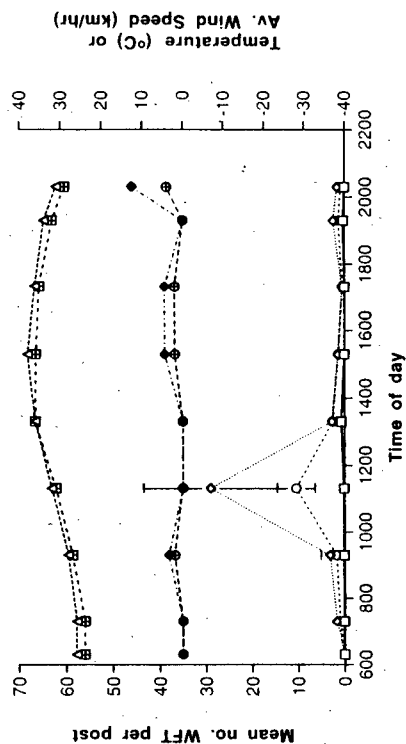


Figure 5.9n Location B 11 July

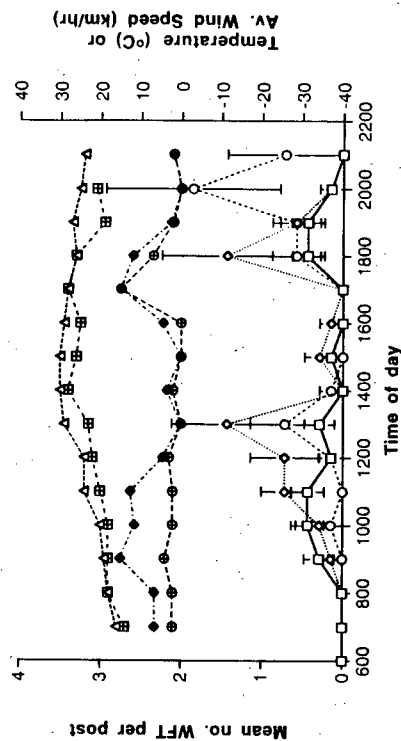
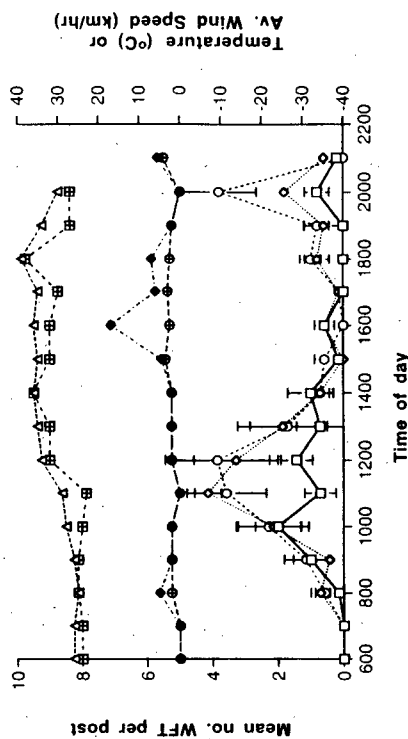


Figure 5.9p Location B 24 July



**Figure 5.9m-p** Hourly patterns of flight in locations A and B for 11 and 24 July. Mean number of WFT per post (from orchard, edge and wild areas combined) are plotted against the temperature at 1.25 m (°C) and at 0.25 m (when different to that at 1.25 m) and the average wind speed at 0.25 m and 1.25 m.

Dark morph female —□— Pale morph female —○—  
 Male —○— Temperature at 1.25m —△—  
 Temperature at 0.25m —●— Av. Wind Speed at 1.25m —■—  
 Av. Wind Speed at 0.25m —●—

Figure 5.9q Location A 19 August

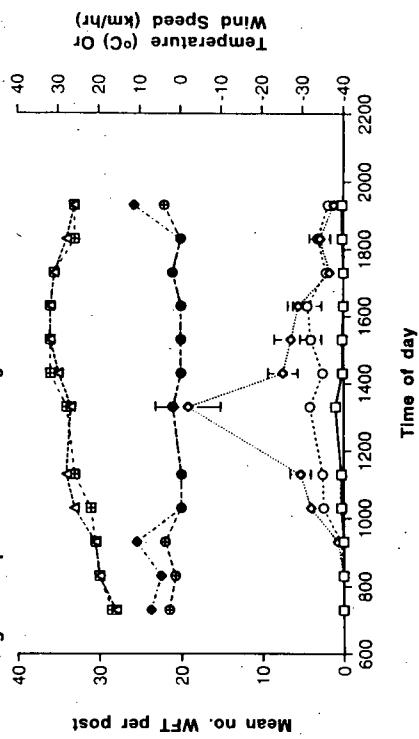


Figure 5.9r Location B 19 August

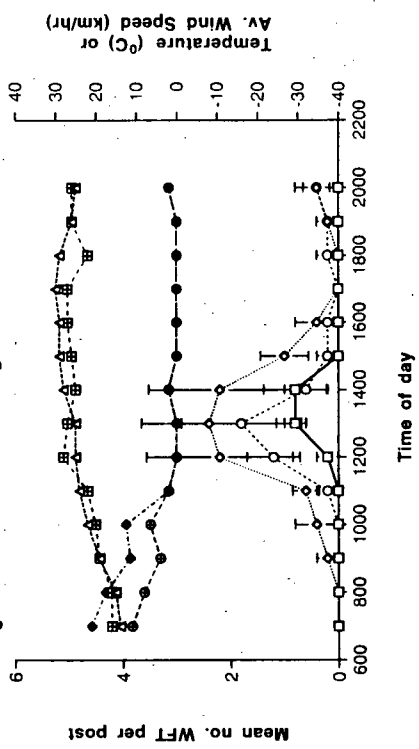


Figure 5.9s Location A 9 October

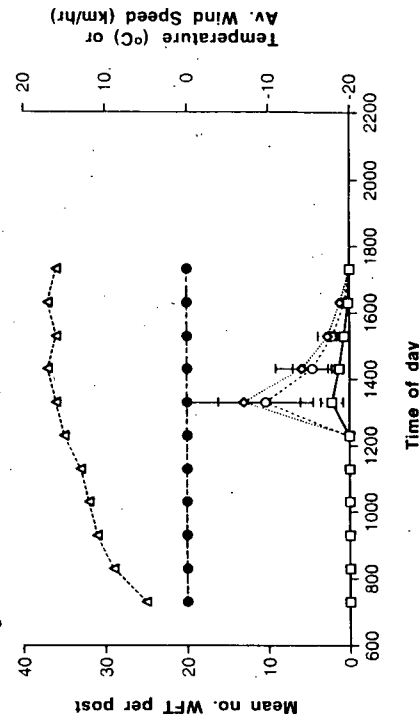
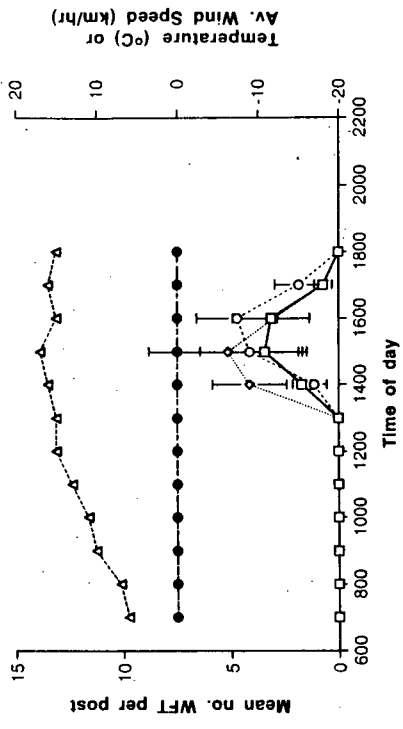


Figure 5.9t Location B 9 October



**Figure 5.9q-t** Hourly patterns of flight in locations A and B for 19 August and 9 October. Mean number of WFT per post (from orchard, edge and wild areas combined) are plotted against the temperature at 1.25 m (°C) and at 0.25 m (when different to that at 1.25 m) and the average wind speed at 0.25 m and 1.25 m.

thrips were still flying in the evening, rather than during the night prior or the early morning of that day (Figure 5.9a). Morning flight on all twelve days did not commence until temperatures were above 15°C (Figures 5.9a-t). Mean density of WFT per post was variable over the season but did show a simple relationship with temperature, with peaks in flight generally coincident with peaks in temperature. Patterns in the two locations were similar with respect to peaks in density, but densities were generally higher in location A than B. On 19 May, conditions were calm and warm and flight in both locations showed a distinct peak around 1400. On 13 and 17 April in area B, the flight activity dropped around 1500, associated with increased winds at this time of day. This was also the case in the afternoons of 30 May (in B only), 13 and 27 June and 11 July, when increasingly strong winds were associated with reduced flight in the orchards, despite ideal temperature conditions. On 24 July, winds were also high from about 1530 until 1800, but the reductions in flight that occurred in both orchards from about midday onwards were more likely the result of temperatures that exceeded 35°C on this day. Conditions were calm on the afternoon of 19 August but flight was again low at that time, probably because of the high temperatures in the afternoon. Note that these figures show the temperatures as taken in the shade, whereas temperatures in direct sunshine were much higher than this (pers. obs). On the final date of study, 9 October, flight did not occur until later in the afternoon, as temperatures were too low for the rest of this day (less than 15°C). On all dates, evening flight ended as soon as dusk commenced, even on those days when temperatures were still ideal for flight.

Wind direction was recorded on each sampling date (Appendix 5.1). Although wind patterns are variable in this mountainous region, there is also considerable consistency in the daily changes in wind patterns. Because of the north-south orientation of this valley, wind flow through the valley generally runs in either a north-east to south-west, or a south-west to north-east direction. On many of the days the wind moved southward in the morning, no doubt the result of cool air moving down the mountain sides.

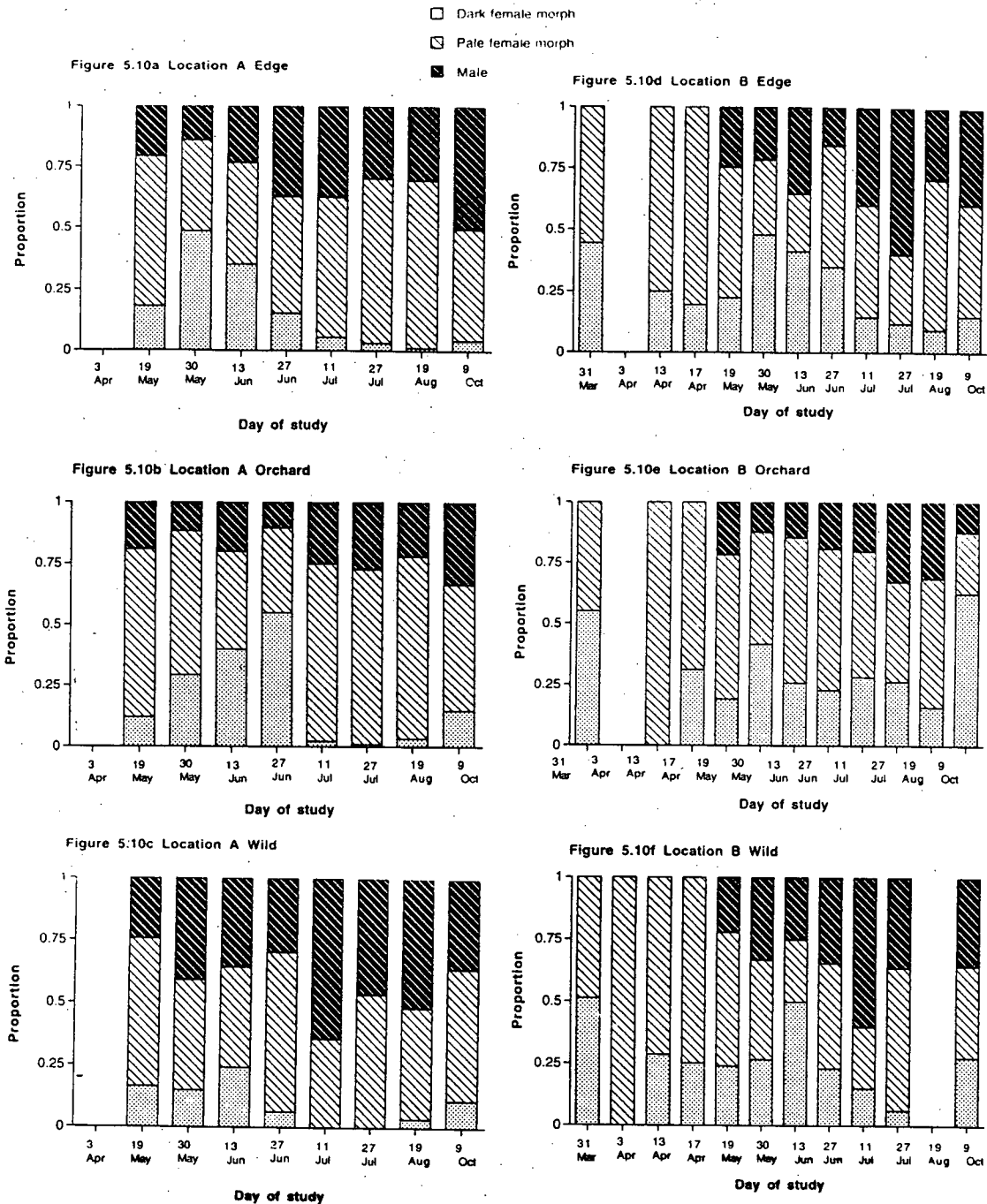
During the day, winds were more variable, but generally followed the length of the valley, whereas by the early evening, winds often moved northward, or towards the north-east, back up the mountain side towards the mountain ridges. On many of the sampling dates in the summer especially, wind speeds picked up during the day, whereas mornings were generally calm. Although high winds in the daytime were often associated with reduced flight of thrips, we did not see any other effect of wind patterns on flight.

On those dates when densities were not too high, I simply dotted each counted thrips with a permanent marker on the sticky card rather than replacing the whole sticky card. This procedure saved both the time and cost of hourly sticky card replacement. One interesting observation made was that over time, there was a loss of approximately 10-15% of the WFT from a sticky card. Whether the insects were able to work themselves free or were blown off, or taken by other insects is unknown.

#### *7) Variation in flight behaviour of colour morphs and sexes of WFT.*

Proportions of the different morphs in flight changed over the season (Figures 5.8, 5.10). Only female WFT overwinter (Pearsall, chapter 2) and these emerged in March and were thus the only sex caught on sticky cards throughout March and April in location B. Males did not appear until the first generation emerged in early May and were thus first caught on sticky cards on 19 May, day 5 of this study. The sex ratio on this date was approximately 4:1 (F:M).

The proportions of the pale morph were generally higher throughout the year than the proportions of the dark morph, except for early spring (31 March) and late fall (9 October) in orchard B. The proportions of the dark morph appeared to be high on 30 May (A & B edge, Orchard B), 13 June (A edge, Orchard A, and B wild land and edge), 27 June (Orchard A), but this was not due to increased numbers of the dark morph, but rather of particularly low numbers of the pale morph on these dates (Figures 5.8, 5.10). In terms of actual numbers of insects, the dark female morph was more common in early spring (31



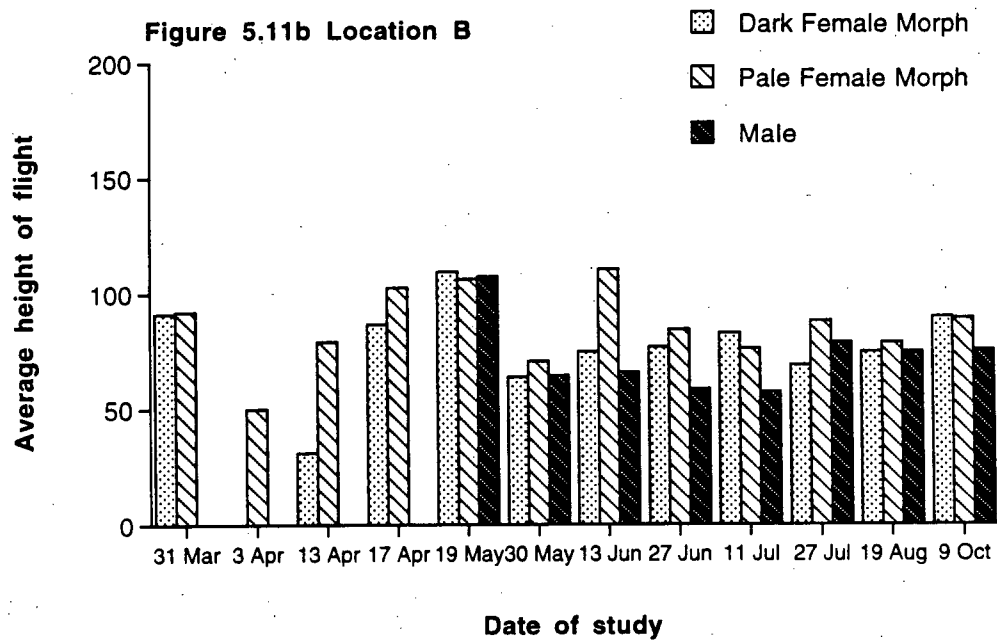
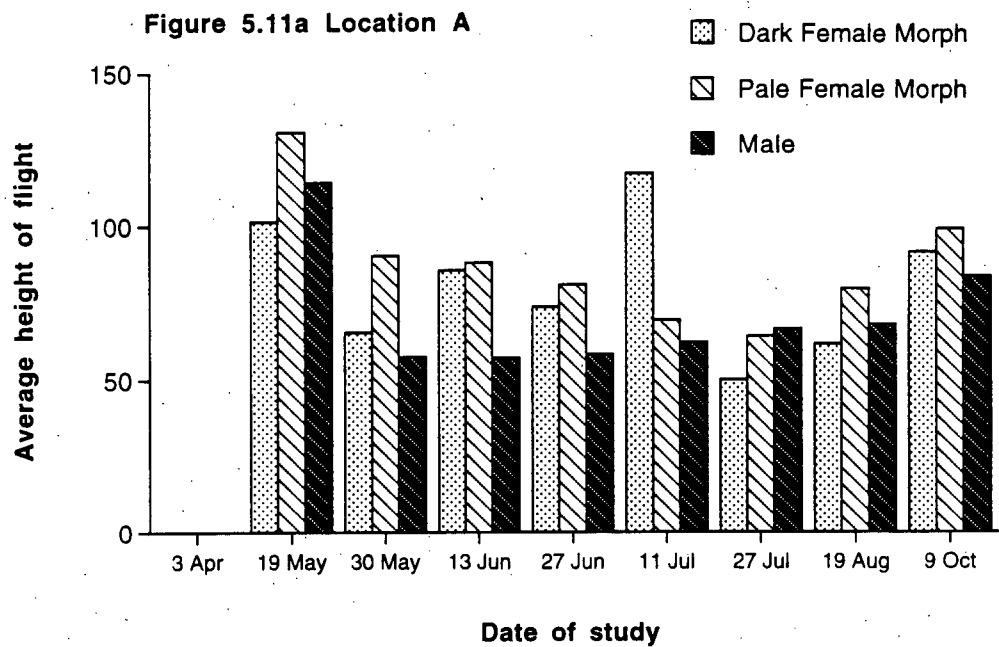
**Figure 5.10a-f** Proportion of the different female morphs (dark and pale) and male WFT of total WFT counts from sticky cards for each sample date in a) edge, b) orchard and c) wild areas of location A and d) edge, e) orchard, and f) wild areas of location B.

March), at emergence of the first generation (19 May) and late fall (9 October) than all other dates in B wild land. In orchard and edge areas of location B, the dark morph was common on 31 March and 19 May only. In location A, the dark morph was at high densities on 19 May in all three areas, peaking only in wild land on 9 October. There were generally greater proportions of darks within orchard A than at the orchard edge and within wild land adjacent to this orchard. Indeed, there were almost no dark females within this orchard on 11 and 24 July (which were the hottest dates of sampling, occurring in midsummer).

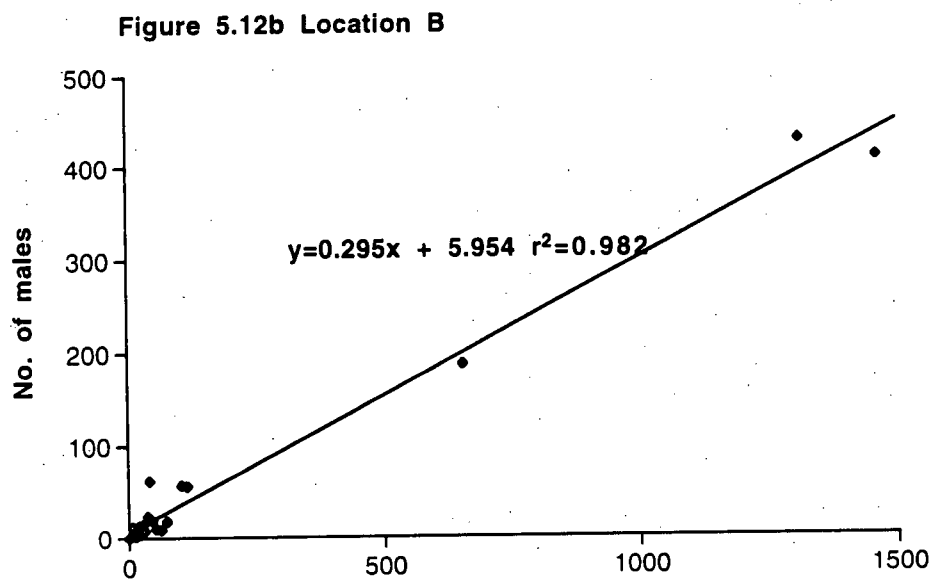
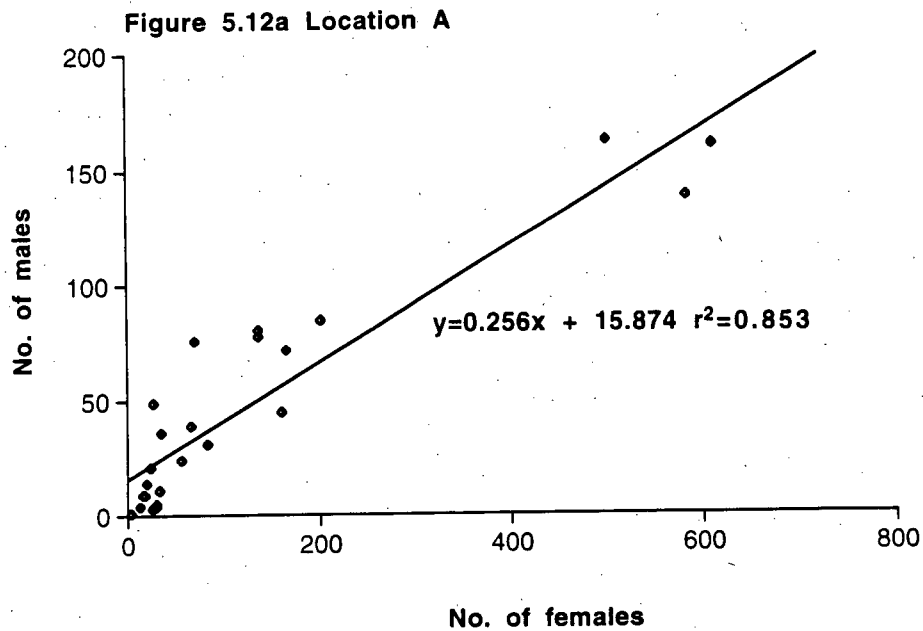
There was no apparent difference in the time of day that males and females commenced or ended their daily flight (Figures 5.9a-t). Males and females of both morphs showed very similar patterns in terms of preferred location over the season (Figures 5.8a-f). All three were most common at the orchard edge for dates between 31 March and 17 April, within the orchard for most dates between 19 May and 24 July, and most common in the wild land for 19 August. However, on 11 July in wild and 24 July in edge posts of B there were unusually high proportions of males on sticky cards. The same was true on 11 July on wild posts in location A. With the exception of these dates in July, however, the proportion of males generally varied around 25% of the total WFT.

There also were no obvious differences in the mean height of flight achieved on a daily basis for males or females of either morph in either location (Figures 5.11a,b).

There was a clear and significant correlation between number of males and females found per post for all areas combined, which indicates that males and females do not appear to behave differently in their patterns of flight ( $\log(x+1)$  transformed data:  $F=78.924$ ,  $df=1,22$ ,  $P=0.000$  for Orchard A;  $F=148.188$ ,  $df=1,22$ ,  $P=0.000$  for Orchard B). Figures given are for untransformed data (Figures 5.12a,b).



**Figure 5.11a,b** Mean height of flight of the two different female morphs (dark and pale) and of males for each sample date for orchard, edge and wild areas pooled in a) Location A and b) Location B.



**Figure 5.12a,b** Relationship between the number of females and the number of males caught per post on sticky cards for edge, orchard and wild areas combined for a) Location A and b) Location B for all dates from 19 May onwards, at which time males had emerged from the ground.



## 5.4 DISCUSSION

Local flight within and surrounding orchards occurred within definite temperature and wind speed ranges. I found that flight was most likely to occur when temperatures were between 17 and 29°C, and when the wind speed was below 15 km per hour. This is to be expected with patterns of such local flight: thrips are unlikely to initiate flight unless conditions are favourable. Lewis (1973) suggested that temperatures of between 17 and 20°C are the usual range of threshold temperatures for take-off for populations of thrips living in temperate regions. However, in a study of WFT in France, Grasselly *et al.* (1993) found that flight of WFT occurred only when minimum temperatures under shelter were above 5°C. I did not find WFT in the air column at temperatures as low as this in the Okanagan. It is possible that temperatures in the open were higher than those taken under shelter. Grasselly and his co-workers did not report on wind conditions for these studies.

Lewis (1973) suggested that individuals or populations of a species will not necessarily have the same temperature threshold, as factors such as sexual condition or rate of maturation of flight muscles at temperatures experienced previously, may affect the threshold. Take-off thresholds for thrips have been assessed using hourly catch data from suction traps and comparing this with the maximum hourly temperature (Taylor, 1963). For these studies it was critical to measure the temperature as close to the insect as possible. Taylor (1962) also suggested that catches may be related more to the amount of time that temperatures are above the threshold level rather than the mean temperature. I did find that WFT were present on sticky cards at lower temperatures in the evening than were found in the morning, no doubt because of the accumulation of heat units earlier in the day which allowed take-off and flight in the case of the former.

In accordance with the studies by Lewis (1973), I found that WFT only flew during the daytime. Lewis (1973) stated that thrips do not take off in the dark, and that they likely need a light intensity of at least 1080lux (100 f.c.) before they will take off. However, he

suggested that in temperate regions, low light intensity will generally not be the limiting factor in the mornings, since it is generally not warm enough for take off before sunrise. I also found, in agreement with his studies, that although it was often warm enough for flight in the evening, fading light about 1-2 hours before sunset reduced catches to zero (Lewis, 1973).

Beckham (1969), in a study of the colour and flight habits of thrips associated with cotton, found that thrips were collected mainly in the afternoon during a study in which sticky traps were placed outside from 0600 to 1200 and 1400 to 2000 daylight periods and 2200 to 0400 evening periods. He found that the thrips associated with cotton, including the tobacco thrips, *Frankliniella fusca* (Hinds), the onion thrips, *Thrips tabaci* Lindeman, the flower thrips, *F. tritici* (Fitch) and *Sericothrips variabilis* (Beach) were all diurnal in habit and only one specimen was collected throughout the period 2200 to 0400 over 5 days of study. Although peaks in catches of WFT often occurred in the afternoon in my study, morning peaks occurred on other days when temperature or wind speeds were limiting in the afternoons.

Lewis (1973) reported that winds up to 6.5-8.0 k.p.h. (4.5 m.p.h) did not prevent take-off, probably because thrips take off into air that is sheltered by surrounding vegetation and thus may not be influenced by the wind speeds in the open air. In our study, flight activity decreased linearly with increasing wind speeds. Although most flight occurred when conditions were calm (zero wind), wind conditions between 3 and 8 km per hour also appeared to be favourable for flight. Thrips are known to be able to tolerate very high wind speeds at least in high-altitude dispersal (Lewis, 1973). However, it is unlikely that thrips are able to direct their course of flight at anything but the very lowest wind speeds: their actual speed of flight is probably dependent upon size: the suggested range of flight speeds varies from about 10 cm/sec for the smallest Terebrantia to 50 cm/sec for the larger Tubulifera (Lewis, 1973). Captures on high sticky traps and at high wind speeds in

our study are no doubt the result of impaction onto cards from thrips being carried passively in the air stream.

Height of flight by WFT was related to both the air temperature, and to the height of surrounding flower stimuli. Mean height of flight did appear to increase linearly with increases in temperature. This may be expected based upon the fact that increased temperatures will lead to thermal updrafts which will carry thrips upwards as outlined in the introduction. Females entering and emerging within orchards early in spring (March, early April) are mainly flying at ground level. Although the days chosen for this study during bloom were too cold and windy for flight to occur, previous work has identified an increase in height of flight as the trees come into bloom (late April) (Pearsall, chapter 4). The Similkameen valley is arid during the late summer, and the only available flowers are those of the orchard ground cover which are maintained by irrigation. Flight within the orchard at this time is mostly at ground level. Height of flight at edges between orchards and wild land areas occurred mainly at a level between 25-100 cm, dependent upon the height of the various weed and wildflower blooms in the case of the former, and sagebrush for the latter. Most thrips in this region appear to be flying at a height of 75 cm in wild land in October during the sagebrush and rabbit brush bloom.

A study by Beavers *et al.* (1971) of the citrus thrips found that they were most commonly captured on sticky cards located at 2.7 m above ground rather than 0.9 or 1.8 m above ground. The authors suggested that this may be related either to the occurrence of the most succulent foliage in the upper portions of citrus trees being preferred by thrips for feeding and oviposition, or possibly due to a negative geotactic or positive phototactic response. It also has been suggested that sticky traps should be placed vertically with the base of the trap situated at or just above the crop canopy in glasshouse crops (Gillespie and Vernon, 1990; Brodsgaard, 1993; Powell and Lindquist, 1992). In our study, however, cards placed at heights of 2 m (coincident with the top of the canopy) caught low numbers

of WFT in the spring, even when the flowers on trees were coming in to the pink stage. In the case of nectarine orchards, it would appear that the optimal location for placement of sticky cards for monitoring purposes would be at the 25-50 cm level early in the spring as this would give most warning to growers of densities of WFT moving into the orchards. Even when conditions are too cold to permit flight at higher levels, it is probable that thrips can simply hop from plant to plant at this low level. Height of flight is no doubt also affected by wind speed. Wind speeds were always higher the greater the distance of the sticky cards above ground level. It is thus not surprising that most flight occurs close to the ground, as even when wind speeds were too high to permit take-off at higher levels, they were often low enough close to the ground, at least to permit this "hopping".

In the case of whiteflies, the general understanding is that catches decrease with height above the ground, which is in agreement with the results of our study (Sharaf, 1982; Gerling and Horowitz, 1984; Rao *et al.*, 1991; Lynch and Simmons, 1993; Liu *et al.*, 1994). Naranjo *et al.* (1995) found that most whiteflies were caught on one-sided sticky traps at ground level on the edges of fields followed by sticky cards located at ground level within fields but suggested no reasons for this.

Density of WFT caught on the sticky cards was correlated with the availability of flowers, as well as generation time. Mean density of thrips was generally greatest at the orchard edge in both orchards throughout the spring to late summer. Later in the summer, densities were greatest at the orchard edge but also within the orchard in the case of orchard B. Western flower thrips populations remain in the orchards even after nectarine bloom probably because of the rich ground cover of dandelions, clover, and other ground cover species which are maintained in these orchard because of irrigation. High densities at the orchard edge may have been the result of the presence of a diversity of different wild flowers and weed species that came into bloom over the summer, whereas there were no longer any nectarine blooms in the orchard and few wild flowers within the wild land. An

alternative suggestion for the generally high densities at the orchard edge may have been due to edge effects. Edge effects in deposition of thrips occurs because of the turbulence caused in the wind along the windward edge of the crop (Lewis, 1973). In this case, the height of the orchard trees creates turbulence which leads to greater densities of thrips on the sticky cards located at the orchard edges as compared with catches in wild land or within orchards. In the fall, densities peaked in the wild land when the sagebrush and rabbitbrush came into bloom, at which time these plants comprised the most significant patches of flowers that are in bloom. Western flower thrips appear to be attracted to the yellow blooms of these flowers and can be found in very high numbers on these plants at this time (pers. obs.).

Although the pale morph was always much more common than the dark morph, it did appear that the dark morph was predominant at cooler temperatures whereas during the summer the pale morph was generally more common. This is similar to the situation as documented in California (Bryan and Smith, 1956) where it has been suggested that the darker morph is more hardy at cold temperatures, whereas the pale morph is better able to withstand the heat of summer. They found that the relative abundance of the colour forms showed no relationship to the type of host. The different morphs of WFT also have been found to predominate in different regions, as found by Sakimura (1962) during her collections of pale forms which were dominant in Paso Robles in central California, and the dark forms from Yuba City in northern California, in late May and early June. She did not mention whether these particular forms were predominant year round, and did not suggest why there may be phenotypic differences in these different locales.

In a previous paper (Pearsall, chapter 2) it was found that the morph ratio of emerging females as captured in emergence traps was heavily biased towards the dark morph (unpub. data), but interestingly, the proportion of the pale morph as caught on sticky cards was much higher. Mound (1967) studied another injurious thripid, *Thrips*

*tabaci* Lindeman and found that those that overwinter are darker than the summer generation females. Felland *et al.* (1993c) also found that most of the female WFT that had overwintered and were recovered in emergence traps in the spring were darker in colouration than those normally found in greenhouses. It may be impossible to determine the absolute ratio of morphs if the pale form is more likely to be captured on sticky cards. The pale morph individual may be more attracted to the yellow sticky cards than the dark morphs, or may have a greater propensity to fly than the dark morphs. The apparent increases in the proportion of the dark morphs throughout late May and June in some areas appeared to be due not to increased numbers of dark coloured females, but rather of particularly low numbers of the pale forms. Population catches on sticky cards were at their lowest at this time of year, probably because of the lack of nectarine bloom and because the ground cover in both orchards was mowed fairly regularly at this time resulting a shortage of blooms. A possible shortage of food or oviposition sites was not the situation at the orchard edge, however, as weed and wildflower blooms were at their highest in density during late May and June in this region (pers. obs). The dark morph appears to be more attracted to dandelion blooms than the pale morph (Pearsall, unpub. data), and thus may have been caught more often on sticky cards after mowing removed this habitat than the pale morph.

Lewis (1973) suggested that in species such as WFT where reproduction is arrhenotokous, males would be expected to make up approximately 20% of the population. Although we did see some variability with location and time of year of sampling, we found that the sex ratio was approximately in accord with this figure, with the proportions of males varying mainly between 20 and 30%. There were, however, some dates when the numbers of males made up 50% or more of the total WFT. The days when males made up higher proportions of the population were in July. At this time, temperatures were at the maximum levels for the year, wild flowers were beginning to dry up and the population

size was generally low. Lewis (1973) suggests that changes in the proportion of males in natural populations may be associated with changes in temperature, although his examples are of populations displaying greater proportions of males at *cooler* temperatures. The fact that these increases in the proportion of males are localised, occurring only in edge or wild locations, and not in all locations at the same time, suggests that they are more likely the result of a greater propensity for males to swarm in these areas at this time of year. Some recent work in Arizona by Matteson and Terry (1992) has suggested that male WFT occur in large single-sexed groups on certain plants/flowers, and that females go to these groups in order to mate. Male and female WFT have been shown to respond similarly to colours during periods of male swarming and non-swarming behaviour, which suggests that males use resource-based areas as aggregation sites (Matteson and Terry, 1992; Matteson *et al.*, 1991). The shortage of blooms available in wild areas at this time of year may lead males to swarm around and land on the yellow sticky cards instead of blooms because they mistake the traps for flowers. The relationship between the number of males and females per card suggests that males may be attracted to females, that they are responding in a similar way to the stimulus of the yellow sticky cards, or that males and females are affected similarly by wind and temperature.

In general, little is known about either the reproductive status of adult female western flower thrips or the sex ratio of populations in the wild. Higgins and Myers (1992) found that adult sex ratios of WFT in cucumber greenhouses were male biased (>60%) at low densities and changed to heavily female biased (<35% males) at high densities. These authors suggested that female WFT colonizing greenhouses in the spring were virgins and thus produced only male offspring. In the field situation in the Okanagan, however, it is likely that most of the females emerging in the early spring were mated before overwintering: although males were present upon the emergence of the new generation in May, they did not by any means make up the bulk of the population. Sexually immature females are believed to make up the majority of thrips in migrating

populations (Lewis, 1973). Perhaps thrips flying into greenhouses in the spring are more likely to be unmated migratory forms, which would account for the differences between my study and that of Higgins and Myers. However, the female biased sex ratios that these authors found at higher densities, are in agreement with those found throughout the season in the Okanagan. Higgins (1991) found that mated females produced 64-69% daughters, and similarly, Trichilo and Leigh (1988) found that female WFT brought back to the laboratory from the field produced 67% daughters. Varadason and Anathakrishnan (1982) also found three to four times as many females as males in seven species of Indian thrips. Vernon and Gillespie (1990) found significantly female-biased sex ratios on a variety of coloured sticky cards in a greenhouse study. Teulon and Penman (1996) found sex ratios between 8.7 to 15.7 female *Thrips obscuratus* (Crawford) to every male in water traps placed in nectarine blocks in New Zealand. As is the case with WFT, this species is arrhenotokous, and thus the authors expected to find 4: 1 (female: male) ratios in this species in accord with work by Lewis (1973). They suggested that females may be more active than males or attracted more strongly to the traps than males. Bailey (1933) examined seasonal variation in sex ratio of the bean thrips, *Caliothrips fasciatus* (Pergande), on several different hosts in California, and found female biased sex ratios varying between 52.5 and 74.3% females. Females are known to live longer than males, about twice as long (40-50 days) in a laboratory study by Bryan and Smith (1956) carried out at 20°C. Thus, we would expect female biased sex ratios in a population that is made up of mated females producing mainly daughters.

We expected to find some differences in flight behaviour among the different female morph types and the sexes because of the varying sizes and colours. However, with so much variability in flight patterns, and only twelve days of comparative data, it is difficult to draw any conclusions regarding flight behaviour of the different sexes and morphs. However, males and dark and pale female morphs did appear to show very similar patterns



of flight behaviour, entering the air column at a similar time of day, and showing similar peaks and troughs in accordance with changes in wind and temperature patterns. Males were still apparent in the air stream when conditions were absolutely calm, suggesting that they are able to take off even when there is zero wind. There did not appear to be any differences in the mean height of flight of the three groups, and all appeared to equally affected by high wind speeds. We did, however, find that in the case of abnormally high temperatures, as were found in wild land locations close to orchard A in both dates of July, no dark WFT were found to be in flight at all. Unlike the pale coloured females and males, the dark females may not have been able to withstand the heat.

Lewis (1973) suggested that since the catch of thrips on a sticky trap is a product both of the aerial density and the wind speed past it, catches at each height should be corrected for the wind speed or it is possible that we may mistakenly identify the preferred height of flight. However, within the range of heights used in this study, wind speed was always directly related to the height of the sticky cards above ground level, with lowest wind speeds always found at the lowest (25 cm) level and highest wind speeds found at the highest (2 m) level. In our case, therefore, correcting for wind speeds would only emphasize further the differences in density among the different levels.

There are several implications suggested from this study. At present, growers in this region tend to prune nectarine trees so they remain low for ease of fruit picking and other orchard operations. Since most early spring flight of female WFT is at ground level, such a strategy may be a disadvantage. Growers have reported that most fruit damage is found in the lower part of the tree canopy (pers. comm.). Possibly, such low early-season flight could be exploited by the use of a ground cover in orchards in which WFT could be trapped and destroyed.

Finally, workers using sticky cards for monitoring WFT in field locations should be aware of how the weather factors discussed above affect WFT flight. In addition, it was clear from this study that about 10-15% of WFT caught on a sticky trap any particular hour were not present one hour later. This suggests that one must be careful in interpretation of catches on sticky cards that have been left for some time out in the field, and no doubt also in the greenhouse situation.

## 5.5 APPENDIX

**Appendix 5.1** Patterns of wind direction per day. c=calm. g=gusty (variable strong >15km/hr and weak <5 km/hr breezes), S=wind blowing towards south (i.e.. northerly wind), N=wind blowing northwards (southerly wind), E=wind blowing towards east (westerly wind), W=wind blowing westwards (easterly wind), SE=wind blowing towards the south-east (north-westerly wind), NE=wind blowing towards NE (south-westerly wind), SW= wind blowing towards SW (north-easterly wind), NW=wind blowing towards NW (south-easterly wind). D=Date. O=Orch.

| D   | O | Time of Day |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |
|-----|---|-------------|---|---|----|----|----|----|----|----|----|----|----|----|----|----|----|
|     |   | 6           | 7 | 8 | 9  | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
| 31  | B | S           | c | S | c  | S  | c  | c  | c  | c  | N  | c  | c  | c  |    |    |    |
| Mar |   |             |   | E |    | E  |    |    |    |    |    |    |    |    |    |    |    |
| 3   | A | S           | c | S | c  | S  | c  | c  | c  | c  | c  |    |    |    |    |    |    |
| Apr |   |             |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |
|     | B | S           | c | c | c  | c  | S  | c  | c  | c  | c  |    |    |    |    |    |    |
| 4   | A | S           |   | S |    | S  |    | g  |    |    | NW | NW | N  |    |    |    |    |
| Apr |   |             |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |
|     | B | S           | S |   |    | S  | SE |    | g  |    |    | NW |    | N  |    |    |    |
| 13  | B | c           | c | N | N  | N  | N  |    | S  | S  | SE | S  | S  |    |    |    |    |
| Apr |   |             |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 17  | B | c           | S | S | S/ | c  | S  | W  | S/ | N/ | N  | N  |    |    | W  | S  |    |
| Apr |   |             |   |   | SE |    |    |    | SW | NW |    |    |    |    |    |    |    |
| 19  | A | c           | S | S |    | c  | c  | c  | c  | c  | c  | c  | c  | c  | c  |    |    |
| Ma  |   |             |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |
|     | B | S           | S | S | S  | c  | c  | c  | c  | S  | c  | c  | c  | c  | N  |    |    |
| 30  | A | c           | c | N | N  | c  | c  | N  | N  | g  | N  | W  |    |    | N  |    |    |
| Ma  |   |             |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |
|     | B | N           | N | N | N  | c  | c  | NE | c  | N  | N  | W  | W  | N  |    |    |    |
| 13  | A | c           | c | c | c  | c  | SE | E  | SE | SE | c  | c  | c  | S  | c  |    |    |
| Jun |   |             |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |
|     | B | c           | c | c | c  | c  | S  | E  | NE |    | E  | E  | c  | S  | c  |    |    |
| 27  | A | c           | c | c | c  | c  | c  | N  |    | N  |    | N  |    | c  | SW |    |    |
| Jun |   |             |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |
|     | B | c           | c | c | c  | c  |    | N  | N  | N  |    | N  |    | W  | c  |    |    |
| 11  | A | S           |   | S |    | g  |    | g  |    | E  |    | g  |    | g  | S  |    |    |
| Jul |   |             |   | E |    |    |    |    |    |    |    |    |    |    |    |    |    |

|     |   |   |   |   |   |    |   |     |   |   |    |    |    |   |   |   |   |
|-----|---|---|---|---|---|----|---|-----|---|---|----|----|----|---|---|---|---|
|     | B | S | S | S | E | NE | g | NE/ | c | E | SE | S  | c  | S | S |   |   |
|     |   |   |   |   |   |    |   | E   |   |   |    |    |    |   |   |   |   |
| 24  | A | c | S | S | W |    | N |     | W |   | W/ |    | c  | E |   |   |   |
| Jul |   |   |   |   |   |    |   |     |   |   | SW |    |    |   |   |   |   |
|     | B | c | c | S | S | S  | c | N   | N | W | W  | SW | SW | N | S | S | S |
| 19  | A |   | S | S | S | c  | c |     | c | c | c  | c  | c  | c | E |   |   |
| Aug |   |   |   |   |   |    |   |     |   |   |    |    |    |   |   |   |   |
|     | B |   | S | S | S | S  | S | c   | c | c | c  | c  | c  | c |   | c |   |
| 9   | A |   | c | c | c | c  |   | c   | c | c | c  | c  | c  |   |   |   |   |
| Oct |   |   |   |   |   |    |   |     |   |   |    |    |    |   |   |   |   |
|     | B |   | c | c | c | c  |   | c   | c | c | c  | c  | c  | c |   |   |   |

## CHAPTER 6

### Flower Preference Behaviour of Western Flower Thrips, *Frankliniella occidentalis* (Pergande)

**ABSTRACT:** Western flower thrips (*Frankliniella occidentalis* (Pergande)) occur on most wildflowers, weed and ground cover flowers in the Dry Central Interior, British Columbia. To determine whether WFT prefer any plants to the extent that they could be used as a trap crop in nectarine orchards, I determined their preference for the various naturally occurring ground cover blooms in a series of choice trials. I also examined how height above ground level within an orchard may affect flower attractiveness. Although WFT showed consistent preferences for various flower types, no ground cover grown presently in the Dry Central Interior appeared to have potential as an effective trap crop. The density of landing WFT was not reduced on less preferred flower types, and WFT distributed evenly over all flowers available. Western flower thrips displayed density dependence only in response to highly scented flowers, and were attracted equally to mixtures of colours and single colours of flowers. There was a consistent preference by WFT in the spring for flowers located at ground level. Female WFT appeared to choose blooms before alighting and to land on the preferred flower type. Males landed on flowers after females and displayed the same preferences for flower types as did females.

**KEY WORDS:** *Frankliniella occidentalis*, flower preference, ground cover, nectarine orchards.

#### 6.1 INTRODUCTION

Nectarines are grown in the Okanagan and Similkameen valleys in the southern interior of British Columbia, Canada. The majority of orchards are either flanked by or located close to areas of wild land. Sagebrush (*Artemisia tridentata* Nutt.) is dominant in wild areas and huge numbers of western flower thrips (WFT) overwinter there (Pearsall,

chapters 2, 4). In the spring, adult thrips migrate into nectarine orchards throughout bud development, and those orchards located on the hillsides receive the highest immigration (Pearsall, chapter 4). Eggs laid by WFT females in the developing buds hatch into larvae near the time of petal fall. Feeding by the larvae at this time causes minute scarring, which can develop into serious surface russetting on the mature fruit. Such fruit is generally downgraded at sale, but if damage is serious enough, the fruit is culled.

In general, control of WFT is difficult worldwide because of this insect's global distribution, high reproductive rate and good dispersal ability (German *et al.*, 1992). There are very few effective and registered insecticides available for control (Steiner, 1990), and most of these are incompatible with biological control programs for other pests (Vernon and Gillespie, 1990). In the Okanagan and Similkameen valleys, there appear to be almost no natural enemies of thrips in early spring in the nectarine orchards and in addition, the thrips in this locality appear to have built up resistance to all the commonly used pesticides (E. Hogue and L. Edwards, pers. comm.). It is therefore essential that we explore cultural control options.

Western flower thrips are believed to prefer flowers which have dense inflorescences (Bailey, 1933). Response of thrips, including WFT, to colour has been studied by several workers (e.g. Brodsgaard, 1989a,b; Yudin *et al.*, 1987; Scott *et al.*, 1989; Gillespie and Vernon, 1990; Vernon and Gillespie, 1990; Teulon and Penman, 1992). These studies have shown that there is significant variation in response to colour depending on the species of thrips and their feeding habits, for example, whether they are anthophilus or grass or foliage feeders (Walker, 1974; Kirk, 1984a). However, results for western flower thrips show that blue, low ultra-violet reflective white, yellow and blue-violet traps are more attractive than green, red, orange, black and high ultra-violet reflective white traps. The pink colour of nectarine flowers is apparently not one of the more preferred flower colours. However, nectarines are the only flowers which bloom at any

significant level early in spring, and this probably accounts for their apparent attractiveness to thrips.

Only female WFT appear to overwinter in the Dry Central Interior (Pearsall, chapter 2). This insect is haplodiploid, with females carrying the diploid genotype, and males the haploid. The progeny of unmated females are haploid males, whereas those of mated females includes primarily females but also some males (Bryan and Smith, 1956, Lewis, 1973). The female WFT emerging in the Okanagan and Similkameen valleys probably mated before they overwintered, as the first generation is a mixture of males and females (Pearsall, chapters 2, 4). The damage to nectarines in this region is primarily the result of first generation larvae feeding on the minute fruitlets prior to husk-drop, rather than oviposition damage or adult feeding early in the spring (Pearsall, chapter 3). The choice of oviposition sites in the early spring is critical to the amount of damage to the nectarine crop. An alternative host plant that bloomed in significant density and that was more attractive than nectarine blooms could provide alternative oviposition sites and thus act as a trap crop to reduce damage to the nectarines. Some of the orchards in this area have ground covers of dandelions, which sometimes bloom before nectarines. In those years, dandelions are both the earliest blooming and most abundant flowering plant in the orchard valleys and large numbers of both adult and larval WFT are found within them (Pearsall, pers. obs.). A ground cover of dandelions may reduce nectarine damage by providing alternative egg-laying sites before the nectarine flowers are available, but this would be effective only if dandelions consistently bloomed before nectarines (Hubscher, 1983).

Although colour preference of WFT has been thoroughly documented, no studies have been carried out to determine whether thrips prefer different flower types and morphologies. Certain flower types may be more attractive due to their scent, or the degree of protection they afford the feeding adult and larval thrips. These differences may affect both fecundity and larval survival. The results of pilot studies carried out in 1993 suggested that there are large differences among different weed and wildflower species in

this region in the species of thrips, the density of WFT, the proportions of the dark and pale morphs of WFT they attract and the density of larvae they contain (Pearsall, unpublished data).

Several workers have suggested that, in general, thrips remain within a flower once they have landed on it. However, it seems unlikely that this is the case in nectarine flowers. In a separate study of thrips population dynamics (Pearsall, chapter 3 ), I found much higher proportions of nectarine buds with larval infestations at petal fall than expected from the incidence of adult thrips per bloom at pink and full bloom. The WFT females in these orchards are likely to have moved from flower to flower rather than laying all of their eggs in a single bloom. An appropriate trap crop for thrips would be a flower type in which a female adult thrips either remained to lay all her eggs (whether these developed or not), or a flower type that she consistently chose over surrounding blooms.

Western flower thrips appear to fly into orchards in the Dry Central Interior primarily at ground level (~25 cm from the ground) particularly in the spring when temperatures are low. Thus a trap crop grown on the orchard floor below the canopy may be an appropriate location (Pearsall, chapters 4, 5). However, there is also the possibility that greater numbers of thrips may be attracted into the orchard by a trap crop, which would then act as a reservoir of thrips for increased oviposition into the nectarine flowers. The appropriate strategy with respect to location for a trap crop would have to be thoroughly investigated. This research was carried out primarily to determine whether thrips prefer different flower types and whether the presence of a preferred flower type could act to reduce thrips densities within nectarine flowers.

In addition to diverting thrips from nectarine flowers to a more attractive flower located elsewhere, it would be desirable to find a method to reduce the attractiveness of the nectarine flowers themselves. One product that has received some attention with regards to its action as a plant repellent against insects, is garlic (*Allium sativum* L.) (Bhardwaj and Gupta, 1992; Scheffler and Dombrowski, 1993; Liu and Stansley, 1995; Gurusubramanian



and Krishna, 1996). Volatiles of garlic bulbs caused egg mortality and reduced larval survivorship in laboratory trials against two cotton pests, the noctuid *Earis vittella* Fabricius, and the pyrrhocorid *Dysdercus koenigii* Fabricius (Gurusubramanian and Krishna, 1996). The active principle of garlic, allicin, also showed nematicidal effects against root knot nematodes, *Meloidogyne incognita* Chitwood on tomato seedlings (Gupta and Sharma, 1993). Garlic extract was also found to be highly repellent against German cockroaches (*Blatella germanica* (L.)), although its effects were seen to diminish over time suggesting the occurrence of habituation processes (Scheffler and Dombrowski, 1993). We decided to explore the use of a repulsive scent, namely the garlic spray (Guardian Spray™, American Biological Corp., Paso Robles, California 93446) which could be applied to the nectarine crop itself and used concomitantly with a trap crop.

The main objectives of this study were therefore:

- 1) To examine the flower preference of western flower thrips, by determining the following:
  - a. If nectarine flowers are a preferred flower type compared to other blooms that are available within orchards at the same time i.e., if the density of WFT per nectarine bloom is significantly reduced if an alternative host flower is present.
  - b. If WFT display density-dependent flower choice in response to increasing flower density.
  - c. If the relative proportion of flower types affects flower choice.
- 2) If thrips are attracted to mixtures of flower colours more than to single colours.
- 3) If the height above ground level of flowers affects WFT choice.
- 4) If female WFT show pre- or post-alighting flower choice.
- 5) If males and females prefer different flowers, and which sex lands first on a choice of blooms.

6) If the density of thrips is greater in nectarine blooms from trees within sections of an orchard where the ground cover blooms are removed as compared with trees in areas where the ground cover is intact.

7) If garlic sprays deter thrips from landing on nectarine flowers.

## 6.2 MATERIALS AND METHODS

### Study Sites

Pilot studies of WFT preference were carried out both indoors and outdoors in 1994. Indoor trials were carried out in glass aquaria within the temperature-regulated greenhouse at the Summerland Agriculture and Agri-Food Canada Research Centre, British Columbia. In addition to temperature and light levels, the numbers of WFT introduced into the chambers could be controlled. However, I felt that outdoor trials could assess the choice by WFT under more natural conditions of light and temperature and therefore studies were also done with natural populations. During 1995, all preference trials were conducted outdoors. Trials were conducted at the edge of two nectarine orchards (A & B) located in the Similkameen Valley. The two orchards chosen for this study were located next to the valley side and thus were close to huge areas of sagebrush and wildflowers. These areas are overwintering sites for WFT and thus, I expected that these orchards would receive high levels of WFT immigration during the early spring.

### Field trials

#### 1) *Preference trials.*

In general, outdoor trials all had the same simple design. The flowers used were collected from the field and rendered thrips-free by 1) by excising them before they had flowered, 2) by collecting flowers that had been caged prior to bloom using 2.9  $\mu$ m Nytex screening to prevent entry by thrips, or 3) by manually removing thrips. In the case of tree fruit blooms, such as pear (*Pyrus communis* L.), sweet cherry (*Prunus avium* (L.)), apple (*Malus domestica* (Borkh.)), peach (*Prunus persica* (L.)), nectarine (*Prunus persica nucipersica* (L.)), crabapple (*Malus baccata* (L.)) and saskatoon (*Amelanchier cusickii* Fern.), I removed large branches in January and February, 1994 and placed these into cold storage at the Summerland Agriculture and Agri-Food Canada Research Centre. Before

experiments were run, we allowed the dormant buds on these branches to come into bloom. This was achieved by placing the ends of the branches in large beakers of water in a heated room. Some branches of saskatoon, nectarine and apple dormant buds were enclosed directly on the trees in January or February with mesh bags made of Nytex material which were sealed with duct tape. These bags were left over the buds until they came into bloom naturally in spring. Finally, for small and open flowers such as common groundsel (*Senecio vulgaris* L.), shepherd's purse (*Capsella bursa-pastoris* (L.)), and most of the other naturally occurring ground cover blooms, we brought these plants, with the roots attached into the laboratory, allowed them to come into bloom in a heated room and then checked manually for thrips. In order to remove thrips we shook the plants vigorously and checked each flower head separately. Finally, in the case of dandelions (*Taraxacum officinale* Weber), we removed large areas of sod containing developing dandelions from another area of British Columbia (the Chilliwack valley) early in the spring. These dandelions did not appear to contain any WFT. These large sections of sod were placed into planting trays and enclosed within a sealed tent in the Similkameen Valley. Upon blooming, these dandelions were found not to contain any WFT, and were used for all trials requiring dandelions. These procedures were used to ensure that flowers did not already contain WFT. Flowers used for trials were each placed into a plastic water pick, and inserted into 40 evenly-spaced holes made in plywood sheets (50 cm by 25 cm). The flowers in each trial were placed into the sheet in a completely randomized design. They were set up at the edge of orchard B where it bordered onto wild land. These trials were carried out in spring as the overwintering generation of females emerged. Experiments were carried out at temperatures of 20-27°C and only when conditions were calm (almost zero wind).

a) *Simple preference trials: two-choice trials with each bloom type presented at equal density. 1. Nectarine vs. ground cover blooms, 2. Nectarine vs. tree fruit blooms*

These trials were carried out to determine whether nectarines are a preferred flower type for female WFT. Separate choice tests were carried out between nectarine and each of six commonly occurring, spring-blooming ground cover species growing in the region. Choices presented were between nectarine and shepherd's purse, henbit dead-nettle (*Lamium amplexicaule* L.), red-stem stork's bill (filaree) (*Erodium cicutarium* (L.)), field chickweed (*Cerastium arvense* L.), dandelion, blue mustard (*Chorispora tenella* (Pallas)) and, groundsel. In addition, I compared the relative preference of nectarine versus blooms of apple, cherry, pear, peach, and crabapple (white, pink and dark pink blooms). For each separate trial, six trays were set up with 8-12 flowers of each type inserted into water picks and randomly placed into each tray. These trials were carried out between 18 and 29 April and in each case, the trays were left outside for a total of three hours. All the water picks for each flower type from one tray were placed into separate Ziploc® bags. The whole water pick was enclosed as the disturbance caused during removal of the flowers from the water picks was found to lead to loss of WFT. The number of WFT per bag (group of 8-12 blooms) was counted immediately in the laboratory. The densities of WFT per bloom were corrected for flower size for all the ground cover blooms. We measured flower area for each bloom type by tracing the outlines of six flowers of each type onto graph paper, taking the mean surface area and adjusted densities of WFT accordingly. In the case of fruit tree blooms, densities were not corrected for flower size since these blooms are all very similar in size. The number of WFT per bloom was compared among the two different flower types using paired t-tests.

b) *Flower Density Trials: no-choice trials with the bloom type presented at increasing densities.*

These trials were performed to determine how WFT response varies with respect to the density of a flower stimulus, that is, to determine if there is density dependent

attraction. Using cherry, apple, and nectarine, separate trials were conducted with between four to seven replicates each of 1, 4, 8, 16, or 32 flowers per tray. The numbers of WFT per bloom were compared across density treatments using one way-ANOVA. The first trial was carried out on 23 April, the second on 24 April and the last one on 25 April. In each case, the trays were placed outside at 1300 and brought in four hours later.

c) *Relative Proportion Trials: two-choice trials with the two bloom types presented at varying proportions.*

I varied the relative proportion of two different blooms in choice trials to determine whether WFT prefers the more common bloom over the less common one. Comparisons were made among pink crabapple and white crabapple (both scented), dandelion and cherry (neither strongly scented), dandelion and apple (latter is scented), and black mustard (*Brassica nigra* (L.)) and saskatoon (latter is scented), although here amount of scent was a personal determination, and this may be very differently perceived by thrips. A total of 24 flowers were placed into each replicate tray. Five to seven replicates of each of the following proportions were presented: a 50:50 mix, 25:75, 75:25, 100:0 and 0:100 of the two different bloom types. Thus, on the 50:50 trays, there were 12 flowers of both flower types from the relevant pairs above. These four trials were carried out between 9 and 20 May. In each case, the trays were placed outside between 1200 and 1600.

## **2) Mixture vs. Single Comparison Presentations.**

Presentations of a mixture of attractive blooms, a mixture of unattractive blooms (where degree of attractiveness had been suggested by pilot studies) and presentations of single flower types were carried out on separate plywood trays to determine whether mixtures of colour are more attractive than a single flower type. This was useful in determining whether a mixture of flower colours would be a more effective trap crop than a single flower type. A total of 24 blooms were placed into each tray. In 1994, the number of WFT landing per flower was compared for six replicate trays for each of a) nectarine

only (single presentation of 12 blooms), b) nectarine, pear and dandelion (attractive mixture with four blooms each) and c) nectarine, groundsel and shepherd's purse (less attractive mixture with four blooms each) using one-way ANOVA. In 1995, the number of WFT landing per flower was compared for six replicate trays for each of a) nectarine and pear (attractive mixture with six blooms each), b) nectarine and shepherd's purse (less attractive mixture with six blooms each) and four replicate trays of c) nectarine only (single presentation of 12 blooms).

### **3) *Flower Height Trials.***

A comparison of the choice of flowers at different heights was carried out during 1994. In these trials I wished to determine whether there is a preferred height for thrips to land on flowers, and whether this changes over the season. Small wooden platforms were constructed (22 by 14 cm) which contained 12 regularly spaced holes. One platform was set up at each of three heights (0.25, 1.25 and 2.25 m from the ground) on each of six posts that were located on the border between wild land and the edge of orchard B. Eight water picks each containing a flower were inserted into each hole in the platform. On any one post, the same flower types were used at every height. These trials were carried out twice using flowers of dandelion and nectarine prior to the occurrence of nectarine bloom within orchards, once at nectarine bloom, and using dandelion only at post bloom (at late petal fall). In each trial the flowers were left outside for a total of four hours (from 1300 until 1700). All the water picks from any one height were placed into a separate plastic bags and examined immediately in the laboratory for thrips.

### **4) *Timing of landing choice.***

It is unclear if thrips tend to stay on the flower that they first land on in these preference trials or whether they make adjustments after landing so that they end up on preferred flowers. I carried out two experiments to examine this outdoors on 18 May

1995. Twelve separate trays of an attractive and two unattractive flowers were set up with seven flowers of each variety placed randomly within the holes in each tray to result in a total of 21 flowers per tray. All the flowers of each variety were collected into separate plastic bags from each of three replicate trays after four periods of time: after 20 minutes, 1 hour, 3 hours and 4 hours. For the first experiment, the trays were all covered with a clear Plexiglas lid after the first interval of time (20 minutes), so that no further thrips were able to land, and thus we could examine whether readjustment by thrips occurred within the different arenas. For the second trial, no lids were placed on top of trays so that we could assess how density and sex ratio on the different blooms varied over time.

#### **5) *Male versus female landing.***

This trial was very similar to the experiment above except that thrips were presented with only one type of bloom. I chose saskatoon flowers because I had large numbers of blooms that were not contaminated with WFT. Eighteen trays of eight saskatoon flowers were set up at 1300 on both 18 and 19 May 1995. Tray covers were not used. All the blooms from each of three trays were collected at various intervals of time: after 1, 1.5, 2, 2.5, 3.5 and 5 hours for one trial, and after 1.5, 2, 2.5, 3, 3.5 and 4 hours for a second trial, placed into three Ziploc® bags, and the male: female ratio was assessed.

#### **6) *Ground cover removal.***

To examine the potential effect of a flowering ground cover on thrips damage to nectarines, I removed ground cover in orchard B in which there was an extremely dense ground cover of dandelions. The orchard was divided into six sections, each containing approximately 20 trees. The dandelions underneath the trees in three of the sections were removed by spraying each area with Roundup™ herbicide from a backpack sprayer. Spraying was carried out before both dandelion and nectarine bloom. Any dandelions that bloomed within the three sprayed sections after the spraying were removed by burning



using a hand-held propane burner. At least 3 trees from each of the six areas were sampled throughout bud development for adult and larval thrips. Twelve buds were removed from each tree on each sampling occasion, placed into a Ziploc® bag and taken back to the laboratory for enumeration of WFT.

### **7) *Garlic trials.***

Sixteen trays each of eight blooms of nectarine were set up outdoors. The blooms of eight randomly chosen trays were sprayed with Guardian™ garlic spray prior to being inserted into water picks and placed in to the tray. The primary ingredients in this spray are garlic extract oil, ginseng extract oil and uguave cactus oil, and the suggested application rate is at a volume of one U.S. Gallon per acre (1:10 oil: water). We sprayed until runoff at the recommended dilution. These trays were left outdoors for 4 hours between 1200 and 1600 on 22 April. This trial was repeated on 20 May, with seven replicates of each treatment (by May, the first generation had emerged and thus counts consisted of both males and females). Finally, this trial was carried out on 21 May with blooms that had been sprayed on 20 May with garlic oil, to determine whether there is a reduction in effectiveness over time. This final trial was carried out with seven replicates (trays of eight blooms each) of the two treatments.

### **Data Analysis**

Normality was assessed using probability plots (SYSTAT GRAPH module). Treatment effects in trials were compared using analysis of variance or paired t-tests where appropriate. Residuals were saved and assessed for homogeneity of variance. Outliers were omitted from the data sets where they resulted in serious heterogeneity of variance and when their omission did not result in a change in the significance level of a test. Post-hoc testing of ANOVA results was carried out using Tukey's honestly significant difference (HSD) test. Where heteroscedasticity precluded the use of parametric tests, and where

numbers could not be adequately transformed, the non-parametric Kruskal-Wallis test was used. A Mann-Whitney U test was used for post-hoc comparisons of all Kruskal-Wallis results with a Bonferroni adjustment to control the experiment-wise probability of a type I error to 5%.

Comparisons cannot be made across trials since these were generally carried out on different days, and thus there were differing numbers of WFT in flight dependent upon the particular environmental conditions.

One concern with these studies was that a comparison of the number of eggs laid on flowers would no doubt be a better indicator of female oviposition preference than merely the number of females per bloom. However, eggs are extremely difficult to count and, for our purposes, the choice of bloom for residence over 3 hours, was deemed as accurate an indicator of female oviposition site as possible.

## 6.3 RESULTS

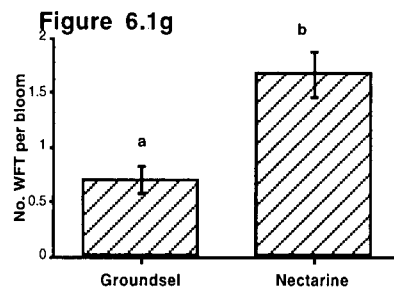
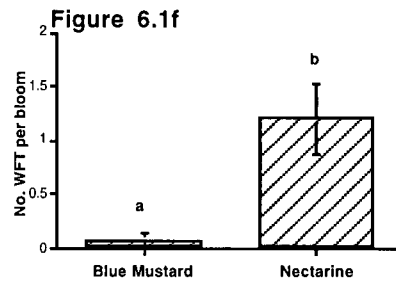
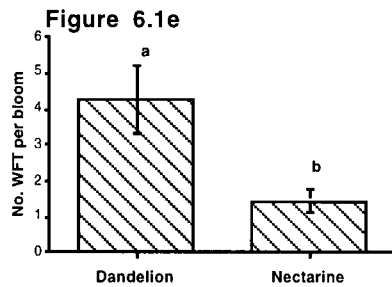
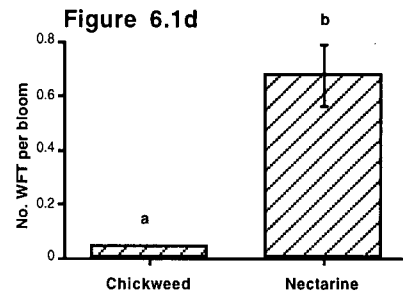
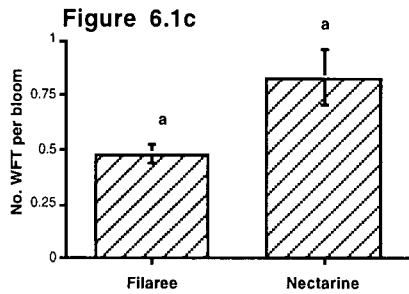
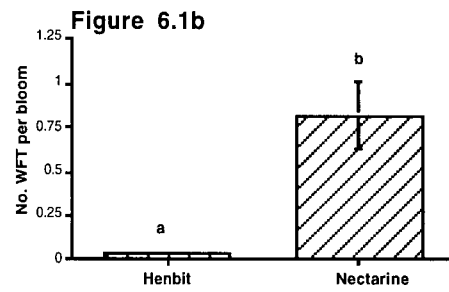
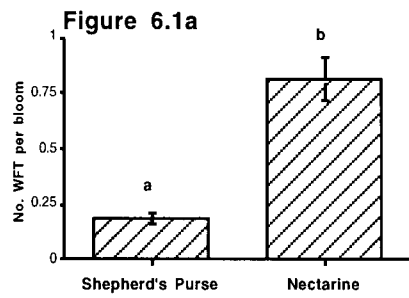
### 1. *Preference trials.*

#### a) 1. *Nectarine vs. ground cover blooms*

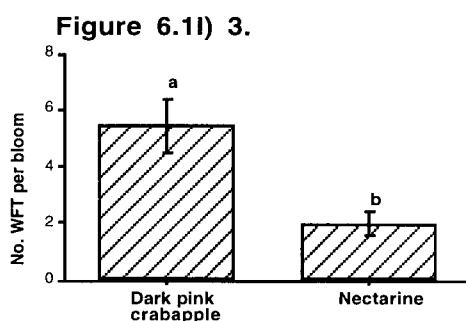
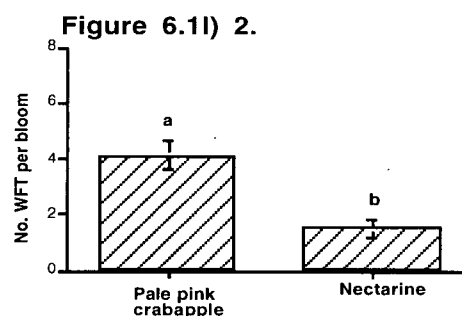
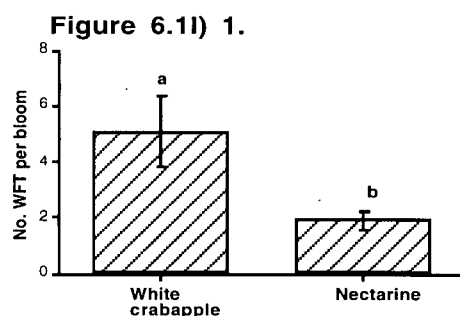
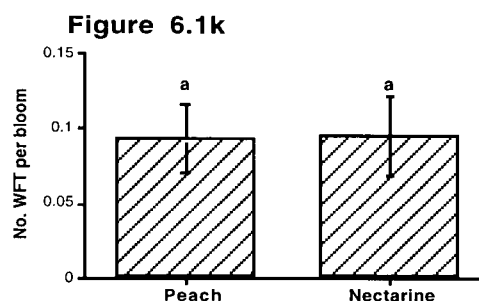
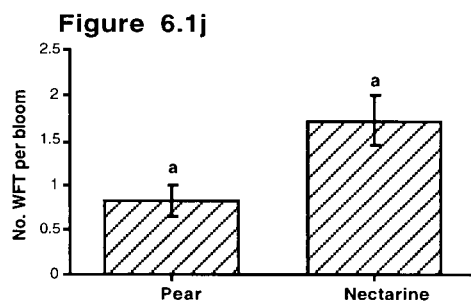
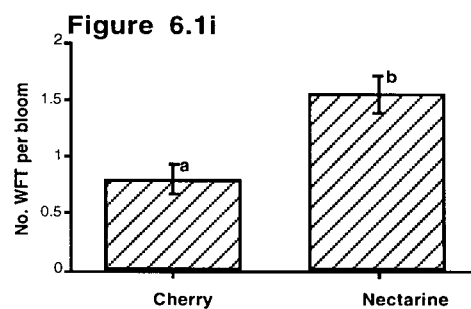
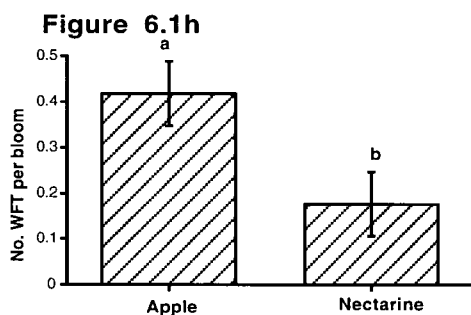
The density of thrips per nectarine flower was significantly greater than all ground covers tested except for dandelion and filaree (paired t-test, nectarine and other flowers, blue mustard:  $T=3.37$ ,  $df=5$ ,  $P=0.002$ ; shepherd's purse:  $T=6.10$ ,  $df=5$ ,  $P=0.002$ ; groundsel:  $T=4.78$ ,  $df=5$ ,  $P=0.005$ ; chickweed:  $T=5.68$ ,  $df=6$ ,  $P=0.001$ ; dead nettle:  $T=4.7$ ,  $df=5$ ,  $P=0.005$ ; dandelion:  $T=-3.94$ ,  $df=5$ ,  $P=0.011$ ; filaree:  $T=2.547$ ,  $df=5$ ,  $P=0.05$ ) (Figures 6.1a-g). There were greater densities of WFT per dandelion bloom than per nectarine bloom, and no significant differences among nectarine and filaree. Most of the ground cover flowers had small and inconspicuous flowers that appeared to be unattractive to this insect.

#### 2. *Nectarine vs. tree fruit blooms*

There were significantly greater densities of WFT per apple bloom and for each of the crabapple blooms than per nectarine bloom (apple:  $T=-3.89$ ,  $df=5$ ,  $P=0.01$ ; dark pink crabapple:  $T=-2.95$ ,  $df=5$ ,  $P=0.03$ ; pale pink crabapple:  $T=-4.49$ ,  $df=5$ ,  $P=0.006$ ; white crabapple:  $T=-2.75$ ,  $df=5$ ,  $P=0.04$ ), no significant differences among nectarine and either pear or peach blooms (pear:  $T=2.23$ ,  $df=5$ ,  $P=0.08$ ; peach:  $T=1.31$ ,  $df=5$ ,  $P=0.225$ ) and significantly greater densities of WFT per nectarine bloom than per cherry bloom ( $T=4.56$ ,  $df=5$ ,  $P=0.006$ ) (Figures 6.1h-l). Peach blooms are identical in appearance to nectarine blooms, and thus we would expect no preference for either bloom type over the other. The preference for apple and crabapple blooms is likely to be due to the highly scented nature of those flowers.



**Figure 6.1a-g** Mean number of WFT landing per flower in two choice preference trials between nectarine and a) shepherd's purse, b) henbit, c) filaree, d) chickweed, e) dandelion, f) blue mustard, and g) groundsel. Different letters above the bars signify statistical differences between the numbers of WFT between the two flower types (paired t-test,  $P < 0.05$ ).



**Figure 6.1h-l** Mean number of WFT landing per flower in two choice preference trials between nectarine and h) apple, i) cherry, j) pear, k) peach, l) crabapple (1.white, 2.pale pink and 3.dark pink). Different letters above the bars signify statistical differences between the numbers of WFT between the two flower types (paired t-test,  $P < 0.05$ ).

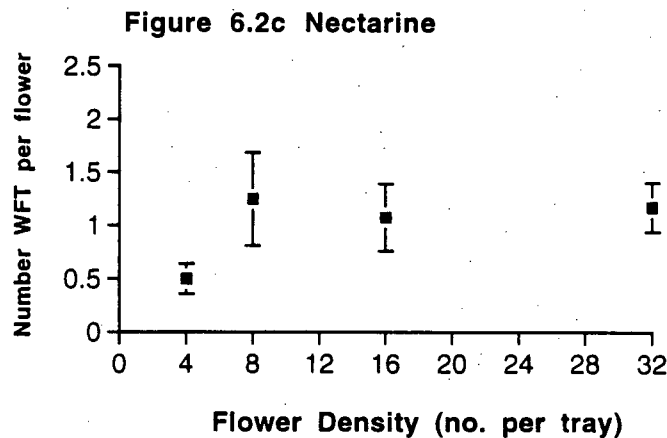
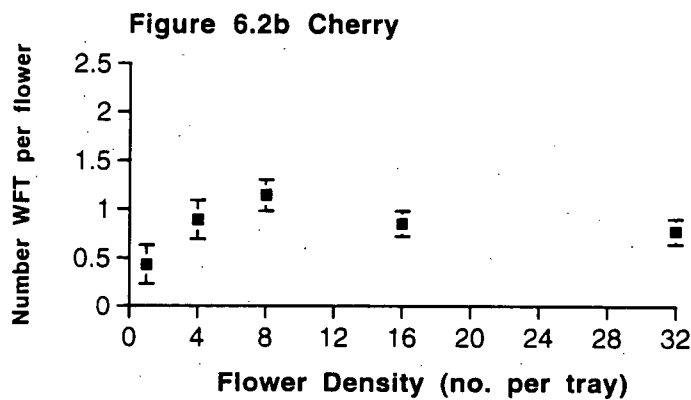
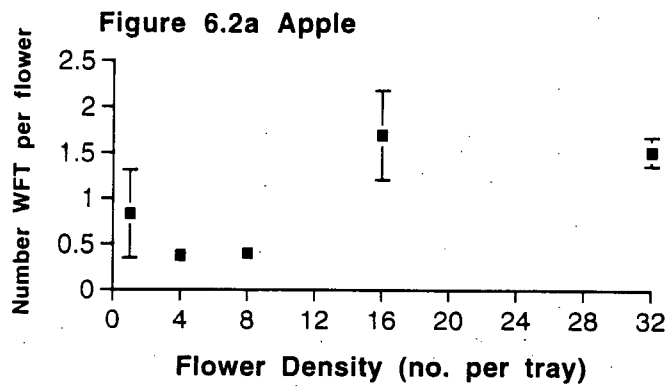
### *b) Flower Density Trials*

Only in the case of single flower presentations were flowers sometimes free of WFT. In the case of apple, ANOVA identified significant differences among densities of flowers ( $KW=14.627$ ,  $4df$ ,  $P=0.006$ ), and post-hoc testing showed significantly more WFT per bloom for the 32 flower presentations than for the 1, 4, or 8 bloom densities. For cherry, there were significant differences among treatments (square-root transformed data,  $F=4.08$ ,  $df=4,30$ ,  $P=0.009$ ), with the lowest densities of WFT found on the single presentations of blooms. In the case of nectarine, there were also significant differences among densities, ( $F=8.71$ ,  $df=3,15$ ,  $P=0.001$ ), with significantly lower densities on the groups of 4 blooms (the smallest density treatment in this case) than all other presentations. Thus, with the exception of the lowest density presentation which had consistently low densities of WFT per bloom for all flower types, there appeared to be a density-dependent landing response only in the case of the highly scented apple blooms (Figures 6.2a-c).

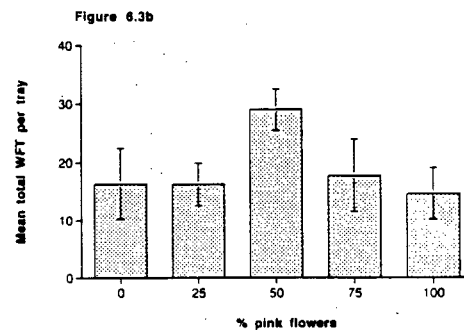
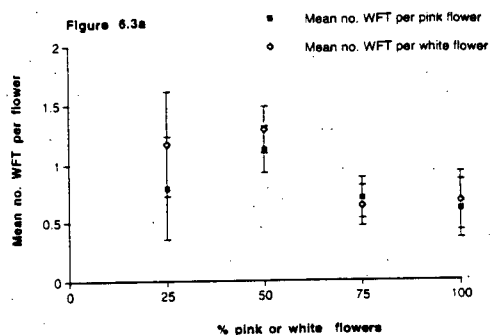
### *c) Flower Proportion Trials*

When I presented two flowers simultaneously but at different ratios, WFT generally showed no preference for flowers either at higher or lower abundance. Only in the comparisons of both unscented and scented blooms were differences sometimes observed, in that more thrips were found in trays with the greatest numbers of the scented bloom. However, in most cases, the numbers of WFT per bloom did not vary in relation to the ratio present.

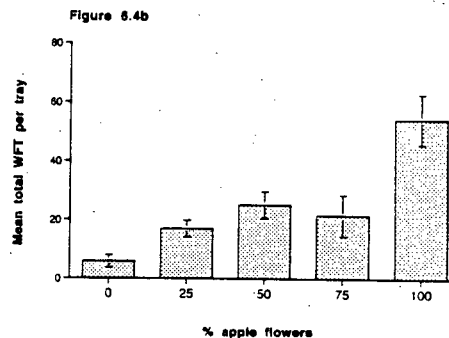
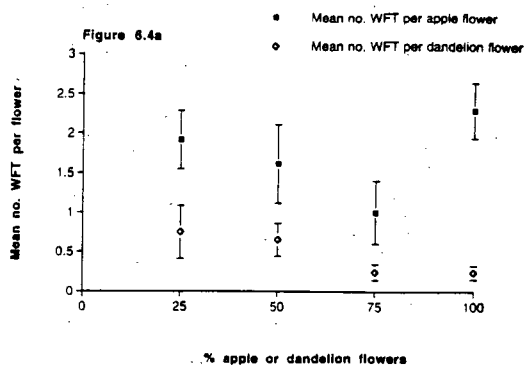
a) Pink: white crabapple (2 scented blooms). Neither the number of WFT per pink flower or per white flower differed among presentations ( $F=1.18$ ,  $df=3,12$ ,  $P=0.36$  for the pink flowers,  $\sqrt{(x+0.5)}$  transformed data:  $F=1.41$ ,  $df=3,12$ ,  $P=0.29$  for white flowers) (Figure 6.3a). In addition, the combined density of thrips landing per flower on each tray did not differ among presentations ( $F=2.17$ ,  $df=4,15$ ,  $P=0.12$ ) (Figure 6.3b).



**Figure 6.2a-c** Numbers of WFT per bloom landing on presentations of a) apple, b) cherry and c) nectarine presented at different densities of blooms per tray (1, 4, 8, 16 and 32 for apple and cherry, and 4, 8, 16, and 32 for nectarine). Significantly lower densities of WFT per bloom were found on the lowest density presentations (one flower of apple and cherry, four of nectarine) than the higher density presentations of the same bloom type. Greater densities of WFT per bloom landed on the 32 flower apple presentation than the other densities of apple flowers.



**Figure 6.3a,b** a) Mean numbers of WFT per bloom for the 25-100% presentations of pink and white crabapple blooms showing no significant differences in the density of landing WFT among presentations. b) Mean number of WFT per tray landing on the five different presentation types showing no significant differences among trays.



**Figure 6.4a,b** a) Mean numbers of WFT per bloom for the 25-100% presentations of apple and dandelion blooms showing no significant differences in the density of landing WFT among presentations of dandelions, although there were more WFT per bloom with 75% apple than with 25% apple. b) Mean number of WFT per tray landing on the five different presentation types showed significantly higher numbers of WFT on the 100% apple presentation than the 100% dandelion presentation.



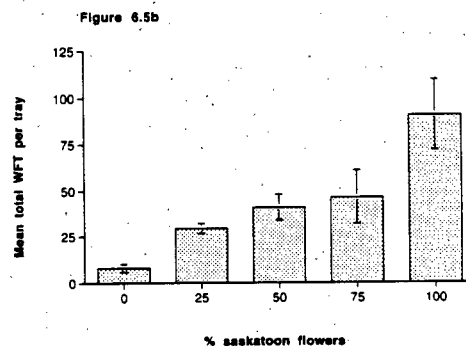
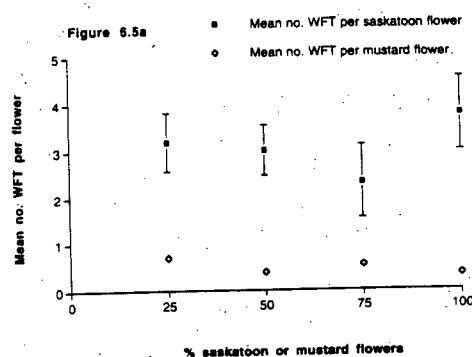
b) Apple: dandelion (1 scented and 1 unscented bloom). The number of WFT per apple flower varied among presentations ( $F=3.72$ ,  $df=3,15$ ,  $P=0.035$ ) with more WFT per bloom when apple blooms made up 100% of the blooms than when only 25% of blooms. The number of WFT per dandelion bloom did not differ among presentations ( $F=1.89$ ,  $df=3,15$ ,  $P=0.18$ ) (Figure 6.4a). The combined density of thrips landing on each tray differed significantly among presentations ( $\sqrt{(x+0.5)}$  transformed data:  $F=5.90$ ,  $df=4,19$ ,  $P=0.002$ ) with significantly higher numbers landing on the 100% apple presentation than the 100% dandelion presentation (Figure 6.4b).

c) Saskatoon: mustard (1 scented vs. 1 unscented bloom). Neither the number of WFT per saskatoon flower or the number of WFT per mustard flower differed among presentations ( $F=0.26$ ,  $df=3,16$ ,  $P=0.85$  for saskatoon,  $F=2.37$ ,  $df=3,16$ ,  $P=0.11$  for mustard) (Figure 6.5a). However, the combined density of thrips landing per flower on each tray differed significantly among presentations ( $F=15.33$ ,  $df=4,19$ ,  $P=0.001$ ), with significantly lower numbers of WFT on the 100% mustard tray than all the others, and higher densities of WFT landing on the 100% saskatoon presentation than the 25 or 50% saskatoon presentations (Figure 6.5b).

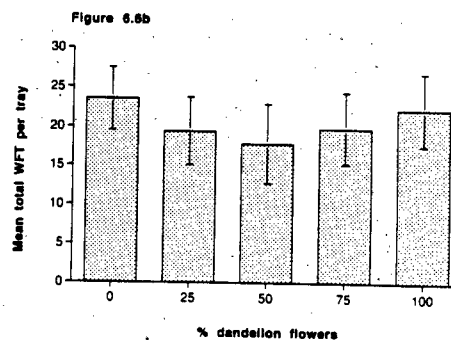
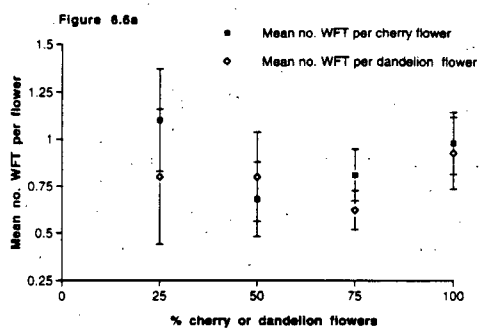
d) Cherry: dandelion (Neither scented). Neither the number of WFT per cherry flower nor the number of WFT per dandelion flower differed among presentations ( $F=0.86$ ,  $df=3,15$ ,  $P=0.48$  for cherry,  $KW=2.16$ ,  $df=3$ ,  $P=0.54$  for dandelion) (Figure 6.6a). In addition, the combined density of thrips landing per flower on each tray did not differ among presentations ( $F=0.34$ ,  $df=4,18$ ,  $P=0.85$ ) (Figure 6.6b).

## 2) *Mixture vs. single presentations.*

1994: Numbers of WFT per nectarine bloom were compared among presentations of pear, nectarine and dandelion versus nectarine only versus groundsel, nectarine and



**Figure 6.5a,b** a) Mean numbers of WFT per bloom for the 25-100% presentations of saskatoon and mustard blooms showing no significant differences in the density of landing WFT among presentations. b) Mean number of WFT per tray landing on the five different presentation types showing significantly lower numbers on the 100% mustard tray than all others and higher densities of WFT on the 100% saskatoon than on the 25 or 50% saskatoon presentations.



**Figure 6.6a,b** a) Mean numbers of WFT per bloom for the 25-100% presentations of cherry and dandelion showing no significant differences in the density of landing WFT among presentations. b) Mean number of WFT per tray landing on the five different presentation types showing no significant differences among trays.

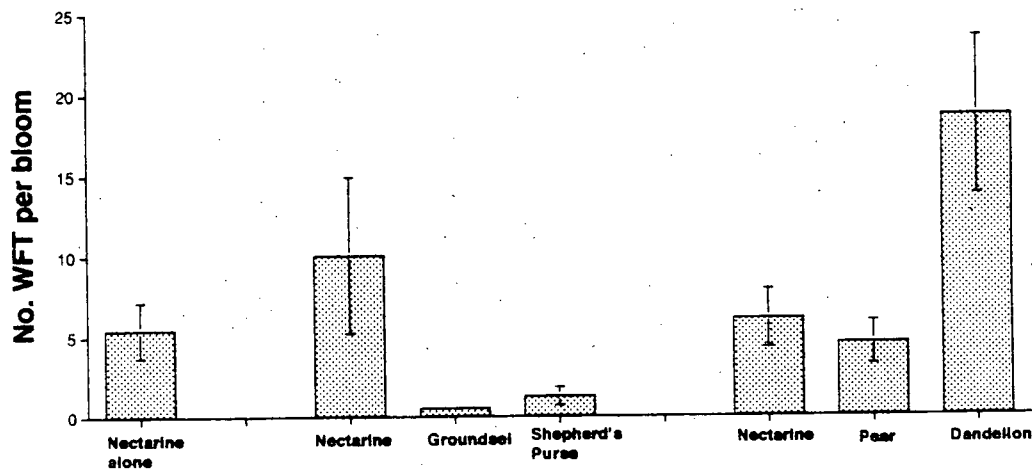
shepherd's purse. The number of WFT per nectarine bloom did not differ significantly among the different presentations ( $\log(x+1)$  transformed data,  $F=0.058$ ,  $df=2,13$ ,  $P=0.94$ ). In addition, the total numbers of WFT landing per flower on each tray did not differ among presentations ( $F=1.043$ ,  $df=2,13$ ,  $P=0.38$ ) (Figure 6.7a).

1995: Number of thrips per nectarine flower differed significantly amongst presentations with nectarines on the attractive tray (pear and nectarine) receiving higher densities than on either of the other two presentations, which did not differ from each other ( $F=5.28$ ,  $df=2,15$ ,  $P=0.018$ ) (Figure 6.7b). In addition, the total number of WFT per tray differed significantly among presentations ( $F=14.97$ ,  $df=2,15$ ,  $P=0.000$ ) with higher numbers of WFT landing on the attractive tray than the other two types.

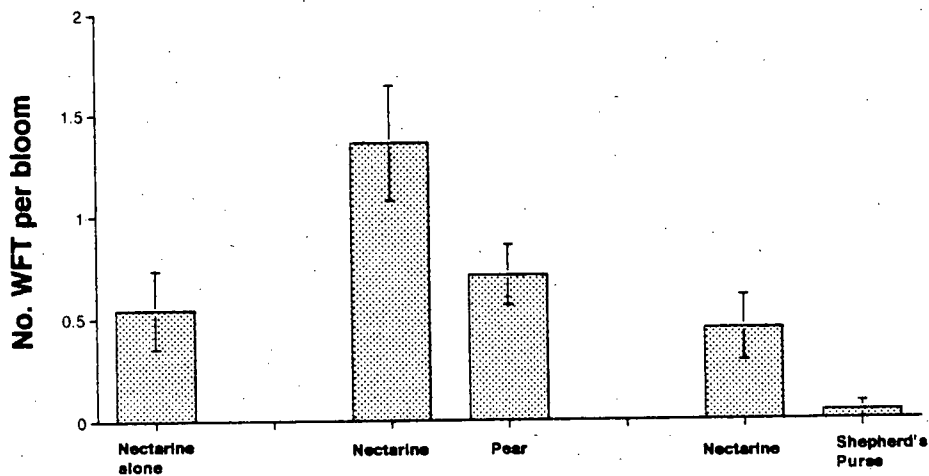
### 3) *Flower Height Trials.*

Western flower thrips preferred to land on the flowers located at ground level (25 cm) in the spring. Densities of WFT differed for both nectarine and dandelion at the three different levels in trials run prior to nectarine bloom (square-root transformed data for nectarine:  $F=9.69$ ,  $df=2,12$ ,  $P=0.003$ ; dandelion:  $F=5.502$ ,  $df=2,12$ ,  $P=0.02$ ), with highest densities overall at ground level for each bloom type (Figure 6.8a). This trial was repeated, and again, there were significant differences in density among the three levels, with highest densities recorded at ground level (nectarine:  $F=6.11$ ,  $df=2,6$ ,  $P=0.036$ ; dandelion:  $F=25.37$ ,  $df=2,6$ ,  $P=0.001$ ) (Figure 6.8b). At nectarine bloom and as temperatures increased in the spring, an increasing proportion of insects occurred in blooms located at higher levels (Figure 6.8c). Although the greatest proportion of WFT were still found at ground level, there were no longer significant differences in densities of WFT caught at the different levels (nectarine:  $F=1.5$ ,  $df=2,6$ ,  $P=0.30$ ; dandelion:  $F=1.43$ ,  $df=2,6$ ,  $P=0.31$ ). The trial held after nectarine bloom was carried out using flowers of dandelion only. Again, with higher temperatures at this time of year, catches of WFT at the

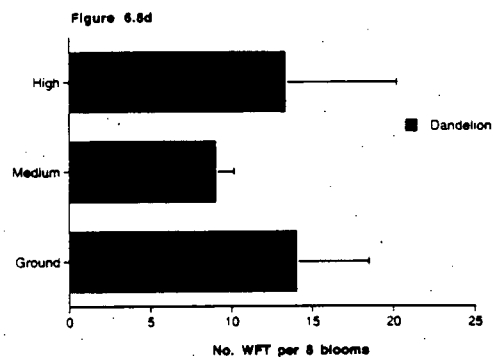
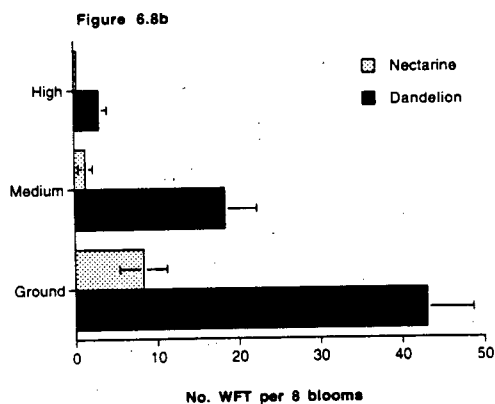
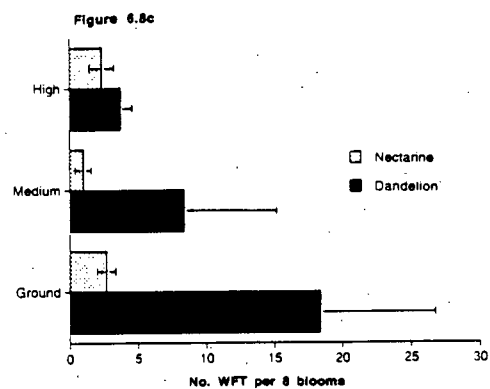
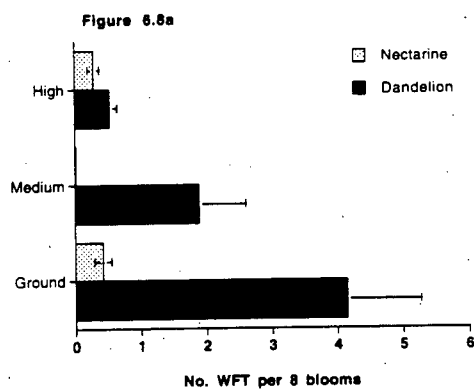
**Figure 6.7a**



**Figure 6.7b**



**Figure 6.7a,b** Numbers of WFT per bloom for comparisons of mixtures of blooms versus single presentations of nectarine blooms. In a) 1994, comparisons of WFT per bloom were made for nectarine alone versus nectarine, groundsel and shepherd's purse versus pear, nectarine and dandelion. In b) 1995, comparisons of WFT landing per bloom were made for nectarine alone versus pear and nectarine versus nectarine and shepherd's purse.



**Figure 6.8a-d** Numbers of WFT per bloom for 3 different heights (high, medium and low) a) for dandelion and nectarine in spring, b) trial a) repeated, c) for nectarine and dandelion at nectarine bloom and d) for dandelion after nectarine bloom. For a) and b) significantly highest densities were found at ground level. For c) and d) there were no significant differences in catches of WFT at the three different heights.

top level tended to be greater than in the early spring, and differences were not significant among heights ( $F=0.23$ ,  $df=2,6$ ,  $P=0.81$ ) (Figure 6.8d).

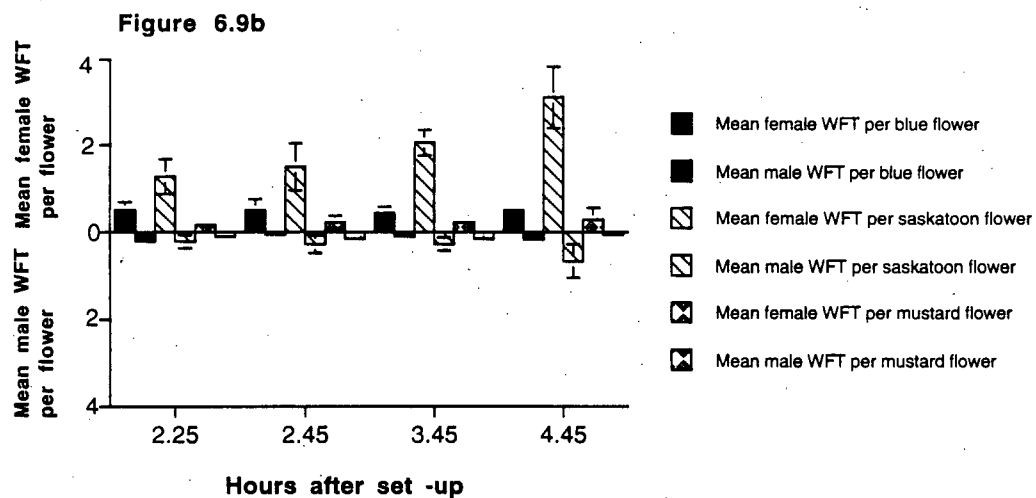
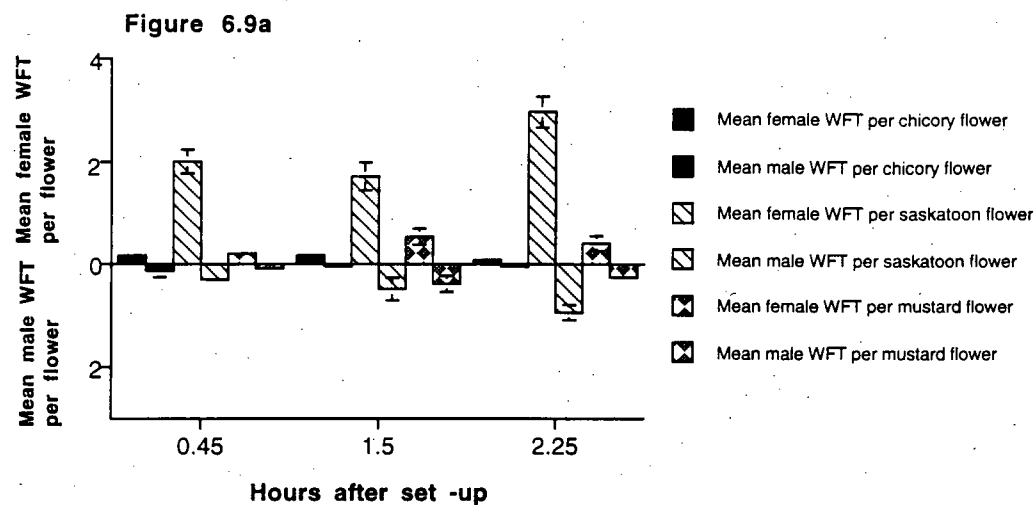
#### 4) *Timing of Landing.*

For both the trials testing the rate of landing by WFT, saskatoon was used as an attractive bloom type. The results of pilot studies carried out during 1994 had shown that WFT were more attracted to blooms of saskatoon than the other flower types used in these trials.

a) The first trial compared the proportion of WFT landing on each of 8 blooms of chicory (*Cichorium intybus* L.), saskatoon and black mustard, and how these proportions varied over time. Flowers from three trays were retrieved after 30 minutes and then lids were placed over the other 6 trays. Three further trays were retrieved after 45 minutes with the final three trays retrieved after a final 45 minutes. The proportions of female WFT on the three bloom types did not vary over the three time periods (chicory:  $KW=0.36$ ,  $df=3$ ,  $P=0.948$ ; saskatoon: arcsin square-root transformed data,  $F=0.55$ ,  $df=3,8$ ,  $P=0.66$ ; mustard: arcsin square-root transformed data,  $F=0.91$ ,  $df=3,8$ ,  $P=0.479$ ) (Figure 6.9a).

b) The second trial compared the proportion of WFT landing on each of 8 blooms of nodding chickweed (*Cerastium nutans* Raf.), saskatoon, and black mustard. No lids were used in this trial. Flowers from 3 trays were retrieved after 2, 2.5, 3.5 and 4.5 hours. Again, the proportion of female WFT on each type of bloom did not vary over the four time periods (nodding chickweed:  $KW=1.98$ ,  $df=3$ ,  $P=0.576$ ; saskatoon: arcsin-square-root transformed data,  $F=0.406$ ,  $df=3,8$ ,  $P=0.753$ ; mustard:  $KW=0.56$ ,  $df=3$ ,  $P=0.906$ ) (Figure 6.9b).

For both of these trials, the number of males per bloom was lower than the number of females, although the males appeared to show the same relative distribution, with highest densities on the saskatoon blooms.



**Figure 6.9a,b** a) Proportion of WFT landing on chicory, saskatoon and mustard after three different time periods, using lids to cover trays after the first time period. Proportion of female WFT did not vary over time on the three bloom types. b) Proportion of WFT landing on nodding chickweed, saskatoon and mustard after four different time periods, without using lids to cover trays. Proportion of female WFT did not vary over time on the three bloom types.

### 5) *Male versus female landing.*

For both trials, female WFT were the first to land on flowers. As the density of females increased, males began to land in low numbers (Figure 6.10a,b).

### 6) *Ground Cover Removal.*

The results from this study showed no difference in the density of either adult or larval thrips per bloom from the areas with or without dandelions (Table 6.1).

**Table 6.1** Mean densities of adults and larvae (20 and 23 April) collected from between 9-15 trees from both areas of dandelion removal and non-removal. Standard errors are given in parentheses.

| Life stage | Date     | Dandelions | No Dandelions | T      | df  | P     |
|------------|----------|------------|---------------|--------|-----|-------|
| Adults     | 12 April | 0.55(0.10) | 0.60(0.10)    | 0.37   | 1,7 | 0.72  |
| Larvae     | 20 April | 3.19(0.49) | 5.09(0.82)    | -2.037 | 1,7 | 0.058 |
| Larvae     | 23 April | 5.08(0.57) | 4.40(0.49)    | 0.921  | 1,4 | 0.372 |

### 7) *Garlic trials.*

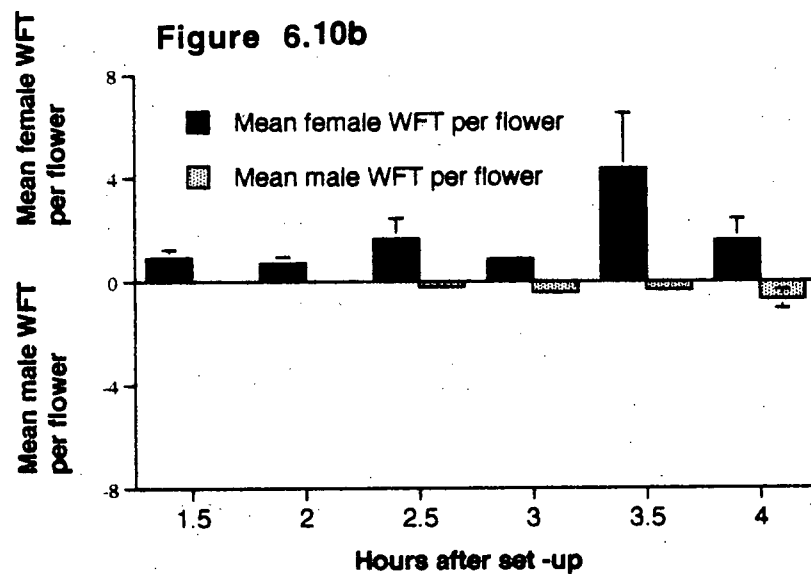
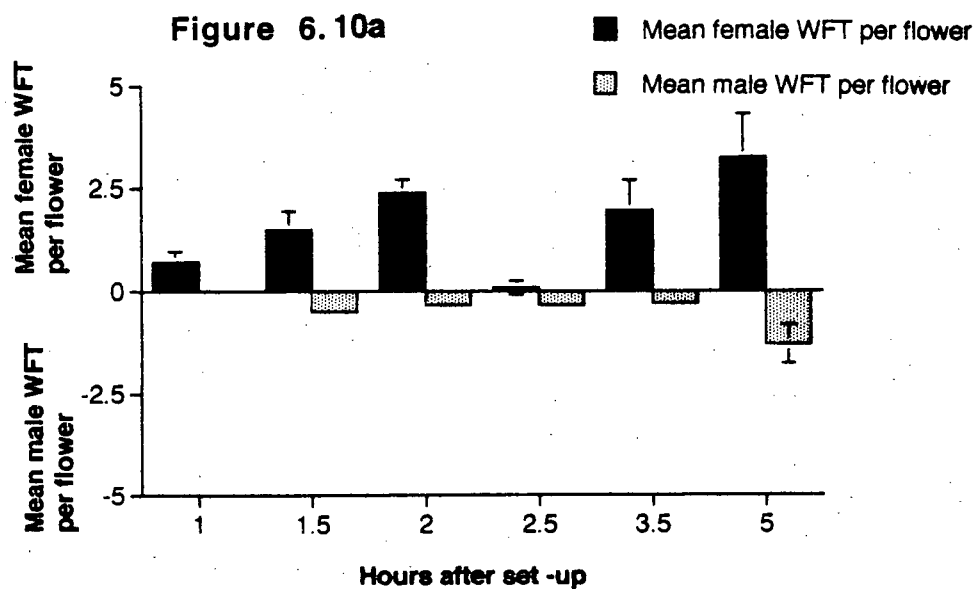
For trial 1, the mean  $\pm$  SEM number of thrips per garlic-sprayed bloom was  $1.15 \pm 0.27$  and  $1.07 \pm 0.14$  per control bloom. There was no significant difference in the density of thrips per bloom between the two treatments ( $T=0.403$ ,  $df=7$ ,  $P=0.699$ ).

For trial 2, the mean  $\pm$  SEM number of thrips per bloom landing on the garlic sprayed blooms was  $4.47 \pm 0.51$  per bloom, whereas there were  $6.27 \pm 0.42$  WFT per control bloom. There were significantly fewer thrips on the garlic sprayed blooms than the control blooms ( $T= -2.736$ ,  $df=12$ ,  $P=0.018$ ).

For trial 3, the mean  $\pm$  SEM number of thrips per bloom landing on the blooms sprayed with garlic one day prior was  $3.91 \pm 0.78$ , and the mean number per control bloom



was  $2.94 \pm 0.62$ . There was no significant difference in the density of thrips landing per tray between the two treatments ( $T=1.813$ ,  $df=6$ ,  $P=0.12$ ).



**Figure 6.10a,b** Mean number of male and female WFT per saskatoon bloom landing over time on trays of saskatoon blooms only. Two trials were carried out and trays were retrieved after a) 1, 1.5, 2, 2.5, 3.5 and 5 hours and b) 1.5, 2, 2.5, 3, 3.5, and 4 hours.

## 6.4 DISCUSSION

*Frankliniella occidentalis* occurs on nearly every flowering plant and is generally characterised as being polyphagous (Lublinkhof and Foster, 1977; Bryan and Smith, 1956). Bryan and Smith (1956) found WFT on 139 plant species in California, and Sakimura (1962) found *F. occidentalis* on 18 different weed and cultivated plant species commonly found near tomato and lettuce plantings in California. More recently, Oliver and Baker (1987) registered 219 species from 59 genera as host plants. The species is also known to concentrate on inflorescences, although it may be found in other locations on a plant (Cranshaw, 1988).

Western flower thrips are the most commonly found species of thrips in and around nectarine orchards in the Dry Central Interior, B.C. (Pearsall, chapters 2, 4). Although they are known to be polyphagous and found on many different plant species, they were found to prefer certain flowers, such as apple and crabapple, over others such as mustard and shepherd's purse. Bautista and Mau (1994) similarly found that WFT were preferentially attracted to different flower types. Yudin *et al.* (1988) compared preferences of thrips for weeds and agricultural crops, and found little variation in preference for lettuce compared with five different weed species. Doerderlain and Sites (1993) found that apparent preferences by WFT for certain plant species were not repeated over the two years of their study. They suggested that WFT exploit certain plants at particular phenological stages, or their preference may be influenced largely by environmental factors. In California, growers of nectarine and other fruits use clean cultivation, namely, removal of all flowering weeds and wildflowers as a strategy to reduce build-up of WFT populations in and around orchards (Bailey, 1938; L. Edwards, pers. comm). Doerderlain and Sites (1993) found that although WFT appeared to prefer certain weed species over onions (their economic crop) in Texas, it was prevalent on all species studied, including onions. There,

as is the case in the Dry Central Interior, the polyphagous behaviour of WFT poses a particularly difficult challenge for pest control. These authors, however, suggested that destruction of weeds could cause WFT to move *into* onion fields, which would be counter-productive.

Our work only examined the preference of WFT for the blooms of various potential ground cover species and some of the tree fruit species grown in the Dry Central Interior. It appears that the strong preferences of WFT for nectarine flowers over the various ground cover blooms makes it unlikely that any ground cover presently growing in the Dry Central Interior could significantly reduce the density of WFT landing on nectarine. Dandelion flowers offered the greatest possibility of success, but because dandelion bloom does not always occur before nectarine bloom, any potential positive effects of growing such a ground cover could not be guaranteed each year. During 1995, although dandelion bloom began before nectarine bloom, the bulk of dandelions bloomed after the nectarines. In addition, there was a cool period just before nectarine bloom, so nectarine buds remained in the pink stage for many days, during which time thrips were able to enter the flower and begin egg-laying. Thus it was not surprising that we did not find any differences in the density of adult and larval WFT in nectarine flowers among areas with and without dandelion ground cover.

WFT appeared to distribute evenly over available flowers, and displayed density dependence only in response to the highly scented apple flowers. The latter observation is expected if flower odour is an important behavioural cue for host-finding, as suggested by Mulligan and Kevan (1973), Kirk (1985) and Teulon *et al.* (1993) among others. Annand (1926) and Appanah and Chan (1981) found that plants with perfume appeared to have greater numbers of thrips on them than plants without perfume. The lack of density dependence in the other cases is interesting since growers in this area have asked whether early pruning and thinning may be a useful strategy to reduce both bloom density and thus the attractive stimulus provided to searching WFT. We did not find any reduction in

density of adult or subsequent larval WFT in trees that had been pruned early in a previous study (Pearsall, chapter 2), and this was corroborated here with the finding that WFT do not show any density dependence in their response to flower density of blooms, unless these are highly scented. We also found that the relative proportion at which a particular flower is presented in choice trials did not appear to influence its relative preference by WFT, although WFT generally appeared to prefer the scented blooms over the non-scented blooms in these trials. My findings suggest, therefore, that a strategy such as using large numbers of trap crop blooms and greatly reducing nectarine blossoms is unlikely to reduce the attack of the nectarine flowers.

The fact that WFT appear to prefer blooms at ground level, particularly in the spring, would however suggest the potential of a ground cover as a trap crop. However, our preference trials illustrated one important fact: even in the presence of a more attractive flower, such as apple or crabapple, WFT still land in appreciable numbers on nectarine flowers. It does not appear that the presence of any bloom, however attractive, will result in complete avoidance of the nectarine flowers. The threshold for cosmetic damage in fruit such as nectarine is too low to permit even minor scarring, thus any egg-laying will likely result in downgrading.

In the comparisons of the mixture versus single bloom types, we had differing results in the two trials, making conclusions difficult. However, it was clear from these trials that the numbers of WFT landing on nectarine flowers were not reduced in the presence of attractive pear blooms. Indeed, in one of the trials, the numbers of WFT landing on nectarine was actually increased in the presence of pear blooms. As mentioned in the introduction, one of the major concerns of using an attractive ground cover is that the more WFT will be attracted into the orchard than would otherwise have occurred.

The choice by female WFT for landing sites appears to occur before alighting as they did not appear to move from poorer flowers to more attractive ones. For the course of these experiments (approximately five hours) adults landing on less attractive flowers

tended to remain there. The proportion of insects on different plant species did change over time such that an increasingly lower proportion of insects were found on the least preferred flowers. Thus, although more WFT chose to land on the attractive blooms, a less attractive flower still received a certain number of WFT.

Female western flower thrips appeared to find and land on blooms before males, which did not land until there was a certain density of females. This could be because there are fewer males present in the population as a whole, and thus it takes them longer to land on blooms, or it may be that males cue into females landing on blooms. Males appeared to show the same preferences for flower types as females, although they may have been responding to female density only. Matteson and Terry (1992) suggested that both sexes use flowers as resource-based aggregation sites, and that males show the same preferences as females. In a study of colour preference in greenhouses, although more females were trapped on differently coloured sticky cards than males in all cases, male and female preference for colour were similar in most cases (Vernon and Gillespie, 1990).

Female WFT were not sufficiently repelled by the garlic spray to recommend this as a useful deterrent spray for nectarine blooms. Results of trials were variable and such inconsistency may have been the result of the spray persisting better on various dates than others. Bhardwaj and Gupta (1992) also found that aqueous extracts of garlic leaves or cloves had no effect on *Thrips tabaci* Lindeman in laboratory experiments, although in Indonesia, field trials intercropping cabbage with garlic was found to result in a reduction in the density of *T. tabaci* (Puspitorini *et al.*, 1992).

In conclusion, there appears to be no ground cover grown presently in the Dry Central Interior that could serve as an effective trap crop. Western flower thrips are found on most flowers growing in the region (pers. obs.), and although they do show consistent preferences for various flower types, such as scented blooms such as apple, lilac, mock orange, and saskatoon, (Pearsall, unpublished data), it does appear that the high mobility of this insect results in its distribution to *all* available flowers, whatever their level of

attractiveness. The presence of highly attractive blooms together with nectarine did not result in greatly reduced densities of WFT landing on nectarine blooms, and suggests that a ground cover would have little success unless it were used in conjunction with a powerful deterrent spray on the nectarine blooms themselves.

## CHAPTER 7

### Effect of Neem Application on Oviposition Choice and Larval Survival of Western Flower Thrips.

**ABSTRACT:** Field trials were carried out to assess the efficacy of neem against damage by western flower thrips [*Frankliniella occidentalis* (Thysanoptera:Thripidae)] on nectarine crops in the Similkameen Valley, British Columbia, Canada. Several trials were conducted over the period between 1993-1995 to assess a) whether neem is effective against adult or larval thrips, b) how the effects of neem differ with concentration, c) whether female WFT are able to recognise and avoid neem-treated flowers, and d) how persistent neem formulations are in the field. Our results show that neem has only limited effectiveness as a control agent against WFT: it has low persistence and does not appear to limit larval development sufficiently to be deemed a possible control agent in the field situation.

**KEY WORDS:** Western flower thrips, *Frankliniella occidentalis*, neem, nectarine

#### 7.1 INTRODUCTION

Western flower thrips (WFT), *Frankliniella occidentalis* (Thysanoptera: Thripidae), cause such serious damage to nectarines in the interior of British Columbia that many growers have begun to consider pulling out their plantings of this crop. Female WFT emerge in early spring after overwintering within orchards and surrounding wild areas (Pearsall, chapter 2). Their first spring flight is well timed with nectarine bloom and thus these flowers are the destination for females searching for both feeding and oviposition sites. Females lay their eggs within the developing flowers from the early spring as buds begin to swell to full bloom (Pearsall, chapter 3). Larvae develop at about the time of petal fall, and their feeding causes minute scarring to the developing fruitlet. As the fruit grows, such tiny scars result in serious russetting that will cause either downgrading or culling of fruit. Larvae fall to the ground to pupate at late petal fall, before the husk splits from the



fruit. Larval hatch within a flower can result in damage in as short a period as two to three days. Adult western flower thrips are highly mobile and it appears that the threshold density for damage in this crop is extremely low (Pearsall, Chapter 3).

WFT is showing increasing levels of resistance to the conventional insecticides used for its control in this region (Thiodan (endosulfan), Guthion (azinophosmethyl) and Diazinon) and there are no promising natural enemies of WFT which could serve for biological control in nectarines (E. Hogue and L. Edwards, pers. comm.). Growers in this region are particularly interested in pursuing natural means of biocontrol that are compatible with the concepts of both organic farming and integrated pest management.

Neem is a possible candidate to serve such a purpose. Extracts from the Indian neem tree, *Azadiracta indica* A. Juss (Meliaceae), contain several compounds that are bioactive against insects, the most potent being the limonoid, azadirachtin. These insecticidal properties include effects on fecundity, vigour and insect growth regulation, oviposition deterrence and, feeding deterrence (Schmutterer, 1990). There are currently four neem products registered in the United States for use as insecticides (Margosan-O, Azatin, Neemix 4.5 and Align).

Neem has been tested against a variety of agricultural insect pests, and some of its most astounding successes have been as a feeding deterrent to a number of lepidopteran pests (Blaney *et al.*, 1990; Isman *et al.*, 1990; Mordue (Luntz) and Blackwell, 1993). Although some groups of insects, such as those with piercing-sucking mouthparts, have been somewhat neglected in laboratory and field trials, there have been some very positive results in trials testing efficacy of various neem formulations against whiteflies, leaf- and planthoppers and aphids (Coudriet *et al.*, 1985; Heyde *et al.*, 1984; Saxena and Khan, 1985; Lowery *et al.*, 1993). Laboratory trials have been carried out against adult and larval western flower thrips on cotton seedlings (Ascher *et al.*, 1992). Although neem formulations did not affect adult female survivorship, fecundity or egg hatch, formulations

of 0.1 and 0.5% Azatin (containing 3% azadirachtin as the active ingredient) did reduce larval survivorship and adversely affected the development of first to second instar.

These results prompted us to examine the effect of neem on western flower thrips oviposition, egg hatch and larval development in outdoor trials on nectarine crops. These trials were carried out over three years in three different orchards, all of which consistently received high levels of thrips damage. During the first year, a trial was carried out to determine whether different concentrations of neem resulted in any reduction in damage to the nectarine crop when applied prior to petal fall. During year two of the study, a trial was carried out to compare the effectiveness of neem as either an oviposition deterrent or a larvicide. During year three, trials were carried out to compare the efficacy and persistence of three different concentrations of neem as a deterrent against adult WFT, as well as to examine the effect on larvae of different timings of neem application at petal fall. In a previous study (Pearsall, unpublished data), the location of thrips within the petal fall buds was observed throughout petal fall. At early petal fall, over 85% of larval thrips were located on the filaments. As larvae developed into second instars an increasing proportion was found feeding directly on the miniature developing fruit. Thus it was proposed that an early petal fall spray would be more effective than one carried out later in petal fall since the former would contact a greater proportion of larvae within the bud than the latter.

## **7.2 MATERIALS AND METHODS**

### **Study sites**

Trials were conducted in two nectarine orchards (orchards A, B) and one block of crabapples (orchard C) located in the Similkameen Valley, in the southern interior of British Columbia. The species of nectarine used for trials was Harblaze in orchard A, a mixture of Crimson Gold and Ruby Gold in orchard B, and the crabapples were of the variety Dolgo in orchard C.

### **Neem formulations**

The product used was a proprietary EC formulation containing neem seed extract (NSE) with 4% azadirachtin (aza) (supplied by Dr. M. B. Isman, University of British Columbia). Dilutions were performed using tap water resulting in azadirachtin at concentrations of 30, 60, 90 and 120 ppm.

### **Methodology**

Data analysis was performed using ANOVA and t-tests from SYSTAT (Wilkinson, 1990). A level of  $P < 0.05$  was taken to be significant for all statistical comparisons. Tukey's HSD test was used for post-hoc comparisons of all ANOVA results.

### **1993: Effect of application concentration**

Neem was applied to 10 trees in orchard A on 12 May before the trees reached the petal fall stage, with five trees sprayed with a concentration of 30 ppm aza and the final five trees with 60 ppm aza. A further five trees were control trees which received no application. These 15 trees were chosen randomly from within three rows of trees in this orchard. Conditions for application of neem on 12 May were warm, calm and sunny with a maximum temperature of 29.7°C. Trees in this orchard were at varying stages of petal

fall, with trees at an overall mean of 65% petal fall (determined by visually assessing the % petal fall for 12 trees and taking the mean). Twelve buds were removed from 10 randomly chosen sample trees on the same day as, but prior to application (12 May) and from all 15 trees five days after application (17 May) and the density of larvae per bud was determined. Buds from each tree were placed in vials of 70% ethanol so that they could be stored for counting later. The vial contents were poured into petri dishes and the buds dissected under a dissecting microscope. Larvae were removed on the tip of a fine camel hair brush as they were counted. Subsequent fruit damage was assessed on these trees when fruit reached the 3 cm stage on 28 June. A total of 15 fruit per tree were assessed for larval damage and rated on a scale of 1-7 (with 1 denoting zero damage and 7 serious russetting of the skin surface). Larval density and fruit damage were compared among treatments to determine whether there was any effect of neem on thrips density or activity.

#### **1994: Effect of time of application: bloom or petal fall?**

On April 13, orchard A received an application of a dormant oil and Thiodan mixture. At the same time, the four rows at one end of the orchard received only a dormant oil treatment. Three sets of nine trees were randomly chosen within the last three rows (trees in the fourth row were used as a buffer). Neem at a rate of 60 ppm aza was applied to the first nine trees on 17 April at 0830 when the trees were at 30% bloom. Conditions were calm, with temperatures at approximately 10°C, with broken cloud. The rest of the day was warm and conditions were calm. At this time only adults were present within buds. The second neem application (60 ppm aza) took place on a second group of nine trees on the afternoon of 21 April, when trees were at early petal fall (only 10% bloom remaining on trees). Again, conditions were calm, with temperatures around 18°C. The final nine trees were control trees, receiving only the application of dormant oil. In this experiment, all trees were sprayed with dormant oil since experience suggested that omission of this application in spring could lead to severe losses from aphid damage.

Neem applications were made on these two dates to determine whether neem could act as an oviposition deterrent or a larvicide. Eight bud samples were taken from nine randomly chosen trees on both 17 and 21 April and from all 27 trees on 25 April, 29 April and 7 May. The fruit on all 27 trees were assessed for damage on 25 May, approximately two weeks after husk fall. Larval enumerations and damage assessments were carried out similarly to 1993. However, this year, a few drops of an aqueous solution of Rose Bengal was added to each vial to stain larvae prior to counting. In addition, contents of each vial were poured through a simple sieve (made with 85µm mesh Nytex screening). The buds were dissected and washed carefully over the sieve and, finally, the total filtrate comprised of larvae from both the fluid and bud portions of the vial was washed into a clean petri dish so that it was suspended in a minimal amount of water. Larvae were then counted as in 1993, using a dissecting microscope. For all larval counts, the densities of WFT at each larval stage (first or second instar) were counted and compared to determine whether neem acts to prevent development of larvae that hatch from eggs within the buds.

**1995: Effect of application of neem at two stages of petal fall, effect of neem as a deterrent to adult females & persistence of neem in the field**

a) A trial was set up in orchard B at petal fall. Applications of neem at 90 ppm aza were made at two different stages of petal fall in this orchard to determine whether neem may be more effective as a larvicide early at petal fall or late petal fall. It is expected that neem would have greater access to the inside of the bud during early petal fall whereas, at late petal fall, the developing fruit has grown to such an extent that the husk tightly adheres to the fruit and the larvae inside the husk are likely to be well protected from any spray droplets. Because temperatures were high at this period of bud development in 1995, these two stages differed in time by only three days.

A total of eight sample trees were used. On 27 April, three control branches per tree were sprayed with water and three early petal fall branches per tree were sprayed with

90 ppm aza using a hand held sprayer. Conditions were overcast, with light wind and 20°C was the high for the day.

On 30 April another three branches on each of the eight sample trees were sprayed with 90 ppm aza. Treated branches, now at the stage of late petal fall, were flagged with coloured tape. Conditions were similar to two days prior although it was slightly more windy.

A third of the available buds (generally between 1-16 buds) from each flagged branch were collected on each of 2 and 8 May and placed into vials of ethanol so that larvae could be counted at a later date. A few drops of an aqueous solution of Rose Bengal were added to each of these vials to stain for larvae. To further facilitate the process of counting larvae, contents of vials were poured into a Buchner funnel, the buds and vials were washed thoroughly and the contents poured into the funnel. Using a Buchner funnel was a very rapid method of separating larvae from the buds and the ethanol in which they had been stored, and the stained pink larvae showed up easily on the white Whatman filter paper so counting could be done very efficiently. Again, larvae were categorized as either first or second instar.

The fruit remaining on each branch were collected from the trees on 22 June and assessed for damage. Damage was graded on a scale of 1-7, where 1 denotes zero damage and 7 severe russetting.

b) A small scale outdoor trial was carried out in orchard C to test the efficacy of different concentrations of neem as a repellent to adult female WFT. The density of female WFT landing on trays of flowers that had been sprayed the same day with concentrations of neem at 60 ppm aza, 90 ppm aza and 120 ppm aza were compared against flowers sprayed with water only. Branches of dormant nectarine buds were brought into bloom indoors, such that the blooms would not become infested with WFT. The branches were cut into sections such that there were three flowers on each small piece of branch. These branch sections were each placed into water picks such that the blooms would remain

hydrated throughout the experiment. Groups of six water picks for each treatment were inserted into slots in wooden trays for a total of six replicate trays for each treatment.

The neem solution was sprayed to runoff on the flowers from a sprayer held 1 m away from each group of flowers, such that coverage was similar to that that would be experienced in large scale outdoor trials. Flowers were sprayed before placing into water picks and into the trays, to be sure that trays did not themselves become coated with neem.

The trays were placed randomly at ground level at the edge of the orchard. These trays were located several metres from any trees, so that tree blooms did not interfere with the trials. The orchard (C) used in these trials was located adjacent to areas of wild land, which is known to be an important source area of thrips (Pearsall, chapters 2,4). After a period of four hours, the flowers from each tray were placed in a bag and stored in a fridge until the adults could be counted. This trial was carried out on 19 May when abundance of WFT was high in this region. Because of our knowledge about the optimal conditions for thrips flight (Pearsall, chapter 5) we chose to perform this a trial on a clear, sunny and calm day so that there would be good sample sizes landing on our trays. Trays were placed outside from 1400 until 1800. The highest temperature recorded in the orchard was 24°C. Because we were interested in the choice by female WFT for flowers, only female densities were compared among treatments. Numbers of males landing on blooms were very low in comparison to female densities.

c) A third outdoor trial was carried out in orchard C to determine how quickly under natural conditions the effects of neem on adult female WFT would deteriorate. This trial was carried out in crabapple trees and the effect and persistence of three different concentrations of neem (60, 90 and 120 ppm aza) were compared. Crabapple was used for this trial as nectarine blooms were no longer available on trees at this time. Both a high density of crabapple blooms and of WFT were present, which ensured that adequate densities of WFT would be collected. Densities of WFT likely would not have been adequate at nectarine bloom to ensure statistical confidence. On April 29 1995, three

samples of 12 crabapple flowers were taken from each of six trees and the number of thrips per bloom was counted, to give a pre-treatment density, and to determine whether there were any differences among trees. Then, one branch per tree was sprayed with the three concentrations of neem until run-off was achieved. A fourth branch per tree was sprayed with a water control. A sample of six flowers per branch were taken on 30 April, 1 May, 2 May and 4 May and placed into separate Ziploc® bags. The number of adult WFT per bag were compared among the four different treatments for each day.



### 7.3 RESULTS

**1993**

Larval density on the two sets of trees destined for the two different neem application rates did not vary significantly prior to application on 12 May (t-test,  $T=1.46$ ,  $df=4$ ,  $P=0.217$ ). There was a significant difference ( $F=4.96$ ,  $df=2,17$ ,  $P=0.02$ ) among the three treatments in the density of larvae per bud on 17 May with significantly lower numbers of larvae per bud in the 60 ppm aza treatment than in the other treatments (Table 7.1). Numbers of larvae in buds on 12 May and 17 May were not compared as these numbers were expected to vary over time as larval hatch continued and as second instars fell to the ground to pupate. The larvae counted on 17 May were not differentiated into 1st and 2nd instars and thus it was not possible to examine whether neem was having any effect on larval development. Adult densities were too low to permit statistical comparisons for either date.

There was no statistically significant effect of neem application on fruit damage per tree ( $F=3.03$ ,  $df=2,22$ ,  $P=0.069$ ). However, the trend was for trees receiving neem at 30 ppm aza to display lower mean fruit damage per tree (mean =3.41,  $se=0.41$ ) than control trees (mean =3.60,  $se=0.20$ ), with trees receiving 60 ppm aza displaying the lowest mean damage per tree of all (mean =2.61,  $se=0.23$ ) (Table 7.1).

**Table 7.1** Density of adult and larval WFT for the three treatments (30 ppm aza, 60 ppm aza and control) and associated damage levels. Twelve buds were sampled from each of 5 trees per treatment. Numbers in brackets denote standard errors. Means for each date followed by the same letter do not differ significantly ( $P>0.05$ ).

| Date             | Control         |                 | 30 ppm aza      |                 | 60 ppm aza      |                 |
|------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| 17/5/93          | Adults          | Larvae          | Adults          | Larvae          | Adults          | Larvae          |
|                  | 0.00(0.00)      | 1.61(0.13)<br>a | 0.04(0.02)      | 1.54(0.12)<br>a | 0.02(0.03)      | 0.83(0.09)<br>b |
| Damage<br>28/6/9 | 3.60(0.25)<br>a |                 | 3.41(0.41)<br>a |                 | 2.61(0.23)<br>a |                 |

## 1994

Larval hatch was just beginning at the time of the second application of neem (21 April) and the density of larvae reached its highest value in control trees on 7 May (Table 7.2). There were no significant differences (all  $P > 0.1$ ) in either larval or adult density per bud between the three treatments (application at bloom, application at petal fall or control) for any of the three dates of collection of petal fall buds (25 April, 29 April or 7 May), although adult densities were too low by the last date to permit statistical comparison (Adults: 25 April,  $\sqrt{(x+0.5)}$  transformed data,  $F=0.11$ ,  $df=2,22$ ,  $P=0.895$ ; 29 April,  $F=2.93$ ,  $df=2,23$ ,  $P=0.074$ ; Larvae: 25 April,  $\log(x+1)$  transformed data,  $F=0.076$ ,  $df=2,22$ ,  $P=0.93$ ; 29 April,  $F=0.10$ ,  $df=2, 24$ ,  $P=0.90$ ; 7 May,  $F=1.61$ ,  $df=2,23$ ,  $P=0.22$ ) (Table 7.3). There also were no significant differences among the three treatments in the proportion of first instars collected for any of the three dates (all  $P > 0.1$ ) (Table 7.4). However, there were significant differences among the three treatments in damage levels ( $F=6.23$ ,  $df=2,22$ ,  $P=0.007$ ), with damage levels significantly lower on those trees receiving a neem application at either date than control trees.

**Table 7.2** Adult and larval density per bud on control trees in 1994 throughout bloom development. Eight buds were sampled from each of nine trees per date. Numbers in brackets denote standard errors.

| Date          | Tree development | Adults per bud | Larvae per bud |
|---------------|------------------|----------------|----------------|
| 17 April 1994 | 30% bloom        | 0.32(0.05)     | 0.00(0.00)     |
| 21 April 1994 | 10% petal fall   | 0.39(0.06)     | 0.04(0.03)     |
| 25 April 1994 | 100% petal fall  | 0.22(0.21))    | 0.50(0.42))    |
| 29 April 1994 | late petal fall  | 0.14(0.04)     | 1.88(1.27)     |
| 7 May 1994    | late petal fall  | 0.00(0.00)     | 2.31(1.09)     |

**Table 7.3** Density of adult and larval WFT for three dates of bud collection (25 & 29 April, 7 May) and associated damage levels for the three treatments (neem application at bloom, neem application at petal fall and control). Number of trees for each treatment = 9. Numbers in brackets denote standard errors. Mean damage levels followed by the same letter do not differ significantly ( $P>0.05$ ).

| Date     | Bloom treatment |            | Petal fall treatment |            | Control      |            |
|----------|-----------------|------------|----------------------|------------|--------------|------------|
|          | Adults          | Larvae     | Adults               | Larvae     | Adults       | Larvae     |
| 25 April | 0.23(0.22)      | 0.73(0.64) | 0.18(0.11)           | 0.81(0.65) | 0.22(0.21)   | 0.50(0.42) |
| 29 April | 0.13(0.04)      | 1.86(0.78) | 0.01(0.01)           | 2.08(1.12) | 0.14(0.04)   | 1.88(1.27) |
| 7 May    | 0.01(0.01)      | 1.30(0.70) | 0.01(0.01)           | 1.84(0.61) | 0.00(0.00)   | 2.31(1.09) |
| Damage:  | 2.95(0.20) a    |            | 3.04(0.20) a         |            | 3.96(0.26) b |            |
| 25 May   |                 |            |                      |            |              |            |

**Table 7.4** Proportion of 1st instar larvae (expressed as a proportion of the total first and second instar larvae) for three dates of bud collection (25 & 29 April, 7 May) for each of the three treatments (neem application at bloom, neem application at petal fall and control). Number of trees for each treatment = 9. Numbers in brackets denote standard errors. Statistics for Kruskal-Wallis testing whether there are differences among treatments in the proportions of first instar larvae.

| Date     | Bloom treatment | Petal fall treatment | Control    | KW   | df | P     |
|----------|-----------------|----------------------|------------|------|----|-------|
| 25 April | 0.93(0.04)      | 0.97(0.03)           | 0.95(0.03) | 2.01 | 2  | 0.367 |
| 29 April | 0.81(0.06)      | 0.93(0.03)           | 0.85(0.04) | 2.17 | 2  | 0.338 |
| 7 May    | 0.34(0.06)      | 0.43(0.06)           | 0.44(0.03) | 2.09 | 2  | 0.35  |

## 1995

a) Application of neem at both early and late petal fall did not reduce larval densities in nectarine buds by either 2 or 8 May when compared with control buds (2 May:  $F=0.62$ ,  $df=2,21$ ,  $P=0.55$ ; 8 May,  $\sqrt{(x+0.5)}$  transformed data,  $F=0.37$ ,  $df=2,20$ ,  $P=0.7$ ). Because these buds were stored in ethanol, it was not possible to distinguish among dead or living larvae. Thus, in order to test whether timing of neem application may be having an effect on development of larvae, we compared the proportion of first instars for each treatment.

Although there were significant differences among treatments for the 2 May collection ( $\sqrt{x}$ -transformed data,  $F=3.85$ ,  $df=2,21$ ,  $P=0.038$ ), with an apparently higher proportion of first instars within the early petal fall treated buds, Tukey's HSD post-hoc test did not indicate any difference among treatments (all  $P>0.05$ ). For 8 May, there were no significant differences detected among treatments in the proportion of first instars ( $KW=0.52$ ,  $df=2$ ,  $P=0.77$ ). Larval numbers were lower on this date than 2 May which suggests that larvae had probably begun to fall to the ground to pupate. Thus, it may not make sense in biological terms to compare either larval density or development among treatments for this date. Finally, fruit damage was compared among the three treatments, to determine whether neem may be having an antifeedant effect against larvae and whether timing of application is critical with regard to this. Again, results were non-significant ( $F=3.30$ ,  $df=2,21$ ,  $P=0.057$ ), although trees receiving control sprays tended to have the highest mean damage and those sprayed early in petal fall the least damage (Table 7.5).

**Table 7.5** Density of larval WFT and the proportion of first instar larvae for two dates of bud collection (2 & 8 May) and associated damage levels for the three treatments (control, neem application at early petal fall, neem application at late petal fall). Number of branches for each treatment = 8. Numbers in brackets denote standard errors.

| Date    | Control         |                 | Early Application |                 | Late Application |                 |
|---------|-----------------|-----------------|-------------------|-----------------|------------------|-----------------|
|         | Larvae          | Propn 1st       | Larvae            | Propn 1st       | Larvae           | Propn 1st       |
| 2 May   | 04.55<br>(0.44) | 62.39<br>(5.43) | 04.03<br>(0.66)   | 75.80<br>(3.64) | 03.68<br>(0.54)  | 60.96<br>(3.15) |
| 8 May   | 02.87<br>(0.31) | 66.20<br>(4.67) | 02.59<br>(0.35)   | 57.84<br>(4.08) | 03.09<br>(0.56)  | 61.62<br>(3.85) |
| Damage: | 06.03(0.27)     |                 | 04.67(0.51)       |                 | 04.86(0.39)      |                 |
| 22 June |                 |                 |                   |                 |                  |                 |

b) There was a significant difference in the density of adult female WFT among the four treatments ( $F=35.32$ ,  $df=3,20$ ,  $P=0.000$ ), with greater numbers of WFT landing on the trays of control flowers than on the neem-treated blooms (Table 7.6). However, there

were no significant differences in female density among the different concentrations of neem ( $P > 0.05$ ).

**Table 7.6** Mean and SE of the number of adult female WFT landing per tray (on a total of 18 nectarine blooms) for each concentration of neem (60, 90 & 120 ppm aza) and the control blooms. Means followed by the same letter do not differ significantly ( $P > 0.05$ ). Sample size = six trays per treatment.

| Treatment   | Mean WFT per tray | SE   |
|-------------|-------------------|------|
| Control     | 31.30 a           | 2.39 |
| 60 ppm aza  | 9.30 b            | 2.09 |
| 90 ppm aza  | 5.17 b            | 1.20 |
| 120 ppm aza | 10.50 b           | 1.61 |

c) No difference was detected among trees in the pre-treatment density of WFT per tree ( $F=0.27$ ,  $df=5,12$ ,  $P=0.92$ ). Mean number of WFT per bloom on this date varied between 0.2 to 0.5 per tree. On both 30 April and 1 May, we found significant differences among treatments in the number of WFT per bloom (30 April:  $\log(x+1)$  transformed data,  $F=4.40$ ,  $df=3,20$ ,  $P=0.016$ ; 1 May:  $F=7.33$ ,  $df=3,17$ ,  $P=0.002$ ) (Table 7.7). Post-hoc tests identified that on 30 April and 1 May, blooms sprayed with 90 ppm aza solution had significantly fewer WFT than control blooms. However, for 2 and 4 May, no significant differences were detected among the treatments (2 May:  $F=0.57$ ,  $df=3,16$ ,  $P=0.65$ ; 4 May:  $F=0.48$ ,  $df=3,12$ ,  $P=0.71$ ).

**Table 7.7** Densities of adult female WFT per bloom for each of the four collection dates (30 April, 1,2 & 4 May 1995) for each of the four treatments (Control, 60, 90 & 120 ppm aza application). Six blooms were sampled from 4-7 trees for each treatment each day. Means for each date followed by the same letter do not differ significantly ( $P>0.05$ ).

| Date     | Control      | 60 ppm<br>aza | 90 ppm<br>aza | 120 ppm<br>aza |
|----------|--------------|---------------|---------------|----------------|
| 30 April | 0.73(0.09) a | 0.47(0.05) a  | 0.39(0.08) b  | 0.60(0.06) a   |
| 1 May    | 0.53(0.20) a | 0.48(0.10) a  | 0.13(0.04) b  | 0.25(0.04) a   |
| 2 May    | 0.79(0.20) a | 0.50(0.19) a  | 0.60(0.10) a  | 0.77(0.20) a   |
| 4 May    | 0.44(0.23) a | 0.51(0.14) a  | 0.26(0.07) a  | 0.47(0.13) a   |

## 7.4 DISCUSSION

Although application of neem both inhibited development and increased mortality of WFT larvae in laboratory trials (Ascher *et al.*, 1992), this did not appear to translate to sufficient efficacy in the field.

Neem did exhibit mild larvicidal properties in the first trial carried out in 1993 but this effect was not apparent in the trials carried out in 1994 or 1995. Although application of neem did result in some reduced fruit damage, this was statistically significant only in one of three trials, and not biologically significant, in that damage levels were still unacceptable. In 1994, although damage was lower on trees with neem application, larval and adult densities in these buds were not affected. This would suggest that neem may have mild antifeedant properties against larvae. Development of larvae from first to second instar was not affected in the trials carried out in 1994. In the third orchard trial in 1995, we focused on the specific timing of neem application assuming that an early petal fall spray would probably impact a greater proportion of larvae than one carried out later in petal fall. Although this early petal fall spray tended to reduce damage more than the other treatments, this was not statistically significant. This early spray also appeared to result in a higher proportion of larvae in the first instar stage on 2 May, but post-hoc testing did not identify this as statistically significant.

One experimental concern was our inability to determine whether there may have been any increased mortality of larvae in neem-sprayed buds because for all trials, buds were collected and stored in vials of ethanol prior to counting. Thus it was not possible to determine whether larvae were alive or dead upon collection. However, the fact that development of larvae from 1st to 2nd instars was not impacted by neem, suggests that the larvae had been alive at the time of collection.

Using the results of larval densities and damage levels, it appeared that neem did not have consistent negative impacts on larval development or mortality in the field and did

not show significant antifeedant properties against WFT larvae. Using our results, we were unable to determine whether neem was effective as either an oviposition deterrent against adult females or as an inhibitor of egg hatch, but this seems unlikely since initial larval densities were generally not reduced in neem treated buds as compared with control buds.

In terms of the impacts directly against adults, neem did appear to show some repellent properties against females in landing trials but it was not able to completely deter females from landing on potential feeding and oviposition sites. In addition, this protective effect appeared to be soon reduced, no doubt because of the low persistence of this chemical under natural elements such as sunlight, wind and rain. There did not appear to be a graded response to the dosage applied, such that neem applied at 120 ppm aza did not result in a larger deterrence than at 60 ppm aza.

In summary, although application of neem did reduce larval densities and damage in some of the trials, these effects were neither sufficiently consistent nor pronounced to make neem an economically viable pest control agent. The different effects of neem on WFT larvae in the laboratory and field situations may be explained not only by poor persistence in the field but also by the limited coverage that is due to these buds having a deep husk into which penetration with fluid chemicals is difficult.

The limitations of neem for use against fruit crops in the field is well recognised (Schmutterer, 1988). Damage levels in fruit and vegetable crops is tolerated only at extremely low levels. This is difficult to achieve with neem, for which the most potent effects are disruption of growth and deterrence of feeding, both which result in a delay in damage reduction. It appears that neem degrades rapidly outdoors, and most success has therefore been found in laboratory and greenhouse situations, although effects of neem seed oil and neem seed extracts against aphids have been found to translate from laboratory to field in some cases (Lowery *et al.*, 1993). These authors suggested that neem was influenced not only by weather conditions and species of aphid, but also by host plant. We



would expect that application of neem on apple buds may result in greater contact with WFT adults and larvae than in nectarine buds, since the latter have a closed husk which provides an ideal shelter for WFT.

The protection afforded to the developing WFT larvae by the tight husk, and the fact that the minute size of the first instars make them difficult to detect in the field situation suggests that successful pest management of this insect will result from reduction of the density of adult females ovipositing in the nectarine flowers. It is necessary to search for a plant protectant such as neem, but one with more potent deterrence against females is clearly required.

## CHAPTER 8

### GENERAL CONCLUSIONS

The western flower thrips is a serious pest of nectarines in this region. Because there does not appear to be any clear relationship between densities of adult WFT, larval WFT and damage, it is not possible to determine the threshold densities of this insect that will result in unacceptable levels of fruit damage. In general, however, it appears that extremely low densities of adult WFT within nectarine buds can result in high enough larval densities for unacceptable levels of damage to ensue. Damage also appears to be highly variable over years and over locations.

Chemical control may be an option when biological control agents are not apparent, and the information I gathered in chapter 3 on location of larvae within the developing fruitlet and the phenology of damage, may assist in allowing growers to better understand the optimal timing for application of pesticide sprays. However, WFT at present show high levels of resistance to the commonly used insecticides in this region, and there is general disinterest in using pesticides due to toxicity to bees and an overall movement towards more organic methods of pest control and fruit production in this region. It is likely that location of plantings and cultural methods of control may be the most critical factors in the success of nectarine production in this region. The information from chapters 2 and 4 illustrated that orchards adjacent to wild land were at particular risk for high immigration of WFT throughout the period of nectarine bud development. For future work, it would be very illuminating if one could set up nectarine plantings within orchards of other fruit trees, such that the nectarine orchards were not adjacent to any wild land, and compare damage levels to fruit in these orchards with fruit in similarly aged plantings of nectarine which were located adjacent to wild land. A well-designed and replicated study could be very valuable.

The results of the various studies that I carried out give an overall picture of the phenology of WFT damage and its biology in this region. This may provide a strong

framework for future studies, both in ecology and pest management. From the pest management perspective, it appears that larvae are so well protected inside buds that it is almost impossible to gain access to them with fumigants or various poisons. Thus, the best strategy for control may be to try and prevent or reduce the amount of egg-laying that takes place on and inside of buds throughout bud development. Unfortunately, the results of the flower preference studies of chapter 6 did not yield convincing evidence for the potential of a trap crop. In addition, the work I carried out with neem also showed that even biological insecticides that show potency in the laboratory, may not show similarly encouraging effects in the field situation. I hope that future studies may yield more light on inhibitors of oviposition which may be useful as an alternative method of reducing egg-laying activity in nectarine buds.

In terms of some of the areas in which my work may be lacking, I would, in future, try to examine flight using sticky cards oriented in the horizontal plane, as there have been various suggestions in the literature that more thrips are caught on cards thus positioned as compared to vertically-oriented sticky cards as used in my studies (e.g. Coli *et al.*, 1992). In addition, I would like to examine the extent of emergence of WFT among rows of nectarine trees, and to compare this among orchards from which ground cover was removed before the end of the season and orchards in which blooms of ground cover remained intact until precluded by cold. Such removal may be useful for orchards in protected locations, such as orchard 'D' in my study.

In terms of recommendations to growers of nectarine in this region, I would suggest that they do not grow low-growing varieties of nectarines nor prune and train trees such that the fruit is at an easy level for manual picking. The clear pattern of maximum movement of WFT into crops at ground level in the spring would suggest that growing tall trees with bloom high above the ground may be a better strategy. Mowing during or prior to the bloom period is also not recommended as this is likely to drive WFT that are present

within ground cover blooms in to the nectarine buds above. I believe that the best chance growers have at present is to show great consideration in the location of new plantings.

Without wishing to appear negative, perhaps it would be most sensible for growers in this region to concentrate on the soft fruits that are not so badly affected by WFT, namely those with a hirsute fruit surface, such as apricots and peaches, particularly if they cannot place new nectarine plantings in protected locations at some distance from wild land. It is clear that this is a region with exceedingly high densities of this highly mobile and highly destructive insect, with an ideal climate for its growth and development, abundant areas of overwintering grounds, and countless sources of blooms into which it is attracted. In order to reduce our use of pesticides, we should concentrate on those species of crop that may most profitably be grown without requiring the application of chemicals.

## LITERATURE CITED

- Ananthakrishnan, T.N. (1971)** Thrips (Thysanoptera) in agriculture, horticulture and forestry- diagnosis, bionomics and control. J. Scient. Ind. Res. 30: 113-140
- Annand, P.N. (1926)** Thysanoptera and the pollination of flowers. Am. Nat. 60: 177-182
- Appanah, S. and H.T. Chan (1981)** Thrips: pollinators of some dipterocarps. Malays. For. 44: 234-252
- Ascher, K.R.S., M. Klein, and J. Meisner (1992)** Azatin, a neem formulation, acts on nymphs of the Western Flower Thrips. Phytoparasitica 20(4): 305-306
- Backus, E.A., W.B. Hunter, and C.N. Arne (1988)** Technique for staining leafhopper (Homoptera:Cicadellidae) ovary sheaths and eggs within unsectioned plant material. J. Econ. Entomol. 81(6): 1819-1823
- Bailey, S.F. (1933)** The biology of the bean thrips. Hilgardia 7:467-522
- Bailey, S.F. (1935)** Thrips as vectors of plant disease. J. Econ. Entomol. 28:856-863
- Bailey, S.F. (1938)** Thrips of economic importance in California. Univ. of California Agric. Exp. Station Circ. 346:24
- Barbour, J.D. and R.L. Brandenburg (1994)** Vernal infestation of thrips in North Carolina peanut fields. J. Econ. Entomol. 87(2): 446-451
- Bartlett, P.W. (1988)** Western flower thrips *Frankliniella occidentalis*. Min. of Agric. Fisheries and Food, Harpenden, Herts, England. Plant Pest Notice Jan. 1988 ref PPH 1291
- Batschelet, E. (1981)** Circular statistics in biology. Academic Press Inc. (London) LTD.

- Bautista, R.C. and R.L.F. Mau (1994)** Preferences and Development of Western Flower Thrips (Thysanoptera: Thripidae) on Plant Hosts of Tomato Spotted Wilt Topovirus in Hawaii. *Environ. Entomol.* 23(6): 1501-1507
- Beavers, J.B, J.G. Shaw and R.B. Hamilton (1971)** Color and height preference of the citrus thrips in a navel orange grove. *J. Econ. Entomol.* 64(5): 1112-1113
- Beckham, C.M. (1969)** Color preference and flight habits of thrips associated with cotton. *J. Econ. Entomol.* 62(3):591-592
- Berlinger, M.J., S. Lebiush-Mordeci, D. Fridja, and N. Mor (1993)** The effect of the types of greenhouse screens on the presence of western flower thrips. IOBC Working Group "IPM Greenhouse Ornamentals" 16(8): 13-16
- Bernardo, E.N. (1991)** Thrips on vegetable crops in the Philippines. In ' Thrips in Southeast Asia'. Asian Vegetable Research and Development Center. pp 5-11
- Bhardwaj, B.S. and R.P. Gupta (1992)** Studies on the effect of plant extract in controlling onion thrips. Newsletter, Associated Agricultural Development Foundation, 12(3): 9-10
- Blaney, W.M, M.S.J. Simmonds, W.V. Ley, J.C. Anderson, and P.L. Toogood (1990)** Antifeedant effects of azadirachtin and structurally related compounds on lepidopterous larvae. *Entomologia exp. appl.* 55: 149-160
- Borden, A.D. (1915)** The mouthparts of the Thysanoptera and the relation of thrips to the non-setting of certain fruits and seeds. *J. Econ. Entomol.* 8:354-360
- Bournier, A. (1970)** Degats des thrips sur nectarines. *Phytoma* 22: 26-29
- Bournier, A. and J. P. Bournier (1987)** L'introduction en France d'un nouveau ravaguer: *Frankliniella occidentalis*. *Phytoma* 388: 14-17
- Boyce, H.R. (1955)** Note on injury to tree fruits by *F. Tritici* (Fitch). *Can. Ent.* 87:238-239

- Broadbent, A.B. (1986)** Growers seek control measures against for western flower thrips. *Greenhouse Canada*. June 1986(6): 8
- Broadbent, A.B., W.R. Allen, and R.G. Foottit (1987)** The association of *Frankliniella occidentalis* (Pergande) (Thysanoptera:Thripidae) with greenhouse crops and the tomato spotted wilt virus in Ontario. *Can. Ent.* 119: 501-503
- Brodsgaard, H.B. (1989a)** *Frankliniella occidentalis* (Thysanoptera:Thripidae)- a new pest in Danish glasshouses. A review. *Dan. J. Plant. Soil Sci.* 93: 83-91
- Brodsgaard, H.F. (1989b)** Colored sticky traps for *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae) in glasshouses. *Z. Angew. Entomol.* 107: 136-140
- Brodsgaard, H.F. (1993)** Cold hardiness and tolerance to submergence in water in *Frankliniella occidentalis* (Thysanoptera:Thripidae). *Environ. Entomol.* 22(3): 647-653
- Brodsgaard, H.F. (1994)** Insecticide resistance in European and African strains of western flower thrips (Thysanoptera: Thripidae) tested in a new residue-on-glass test. *J. Econ. Entomol.* 87(5): 1141-1146
- Bryan, D.E. and R.F. Smith (1956)** The *Frankliniella occidentalis* (Pergande) complex in California (Thysanoptera:Thripidae). *Univ. California Pub. Ent.* 10(6):359-410
- Byrne, D.N. and M.A. Houck (1990)** Morphometric identification of wing polymorphism in *Bemisia tabaci* (Homoptera: Aleyrodidae). *Ann. Entomol. Soc. Am.* 83: 487-493
- Bullock, J.A. (1963)** Extraction of Thysanoptera from samples of foliage. *J. Econ. Entomol.* 56:612-614
- Buntin, G.D. (1994)** Developing a primary sampling program, pp. 99-118. *In* L.P. Pedigo and G.D. Buntin (Eds.), *Handbook of sampling methods for arthropods in agriculture*. CRC, Boca Raton, FL.
- Buntin, G.D. and R.J. Beshear (1995)** Seasonal abundance of thrips (Thysanoptera) on small grains in Georgia. *Environ. Entomol.* 24: 1216-1223

- Chamberlin, J.R., J.W. Todd, R.J. Beshear, A.K. Culbreath, and J.W. Demski (1992)** Overwintering hosts and wingform of thrips, *Frankliniella* spp., in Georgia (Thysanoptera: Thripidae): Implications for management of spotted wilt disease. Environ. Entomol. 21(1):121-128
- Chambers, W.S. and R.W. Sites (1989)** Overwintering thrips fauna in croplands of the Texas South Plains. Southwest. Entomol. 14: 325-328
- Chander, R. and K.L. Verma (1978)** A technique of sampling blossom thrips of apple. Ind. J. Ent. 40:453
- Chellemi, D.O., J.E. Funderburk, and D.W. Hall (1994)** Seasonal abundance of flower-inhabiting *Frankliniella* species (Thysanoptera: Thripidae) on wild plant species. J. Econ. Entomol. 23:337-342
- Childs, L.F. (1927)** Two species of thrips injurious to apples in the Pacific Northwest. J. Econ. Entomol. 20:805-809
- Chisholm, I.M. and T. Lewis (1984)** A new look at thrips (Thysanoptera) mouthparts, their action and effects of feeding on plant tissue. Bull. Ent. Res. 74: 663-675
- Cho, J.J., R.F.L. Mau, T.L. German, R.W. Hartman, L.S. Yudin, D. Goncalves, and R. Provvidenti (1989)** A multidisciplinary approach to management of tomato spotted wilt virus in Hawaii. Plant. Dis. 73:375-383
- Cho, K., C.S. Eckel, J.F. Walgenbach, and G.C. Kennedy (1995)** Spatial distribution and sampling procedures for *Frankliniella* spp. (Thysanoptera: Thripidae) in staked tomato. J. Econ. Entomol. 88(6): 1658-1665
- Coli, E.M., C.S. Hollingsworth, and C.T. Maier (1992)** Traps for monitoring pear thrips (Thysanoptera:Thripidae) in maple stands and apple orchards. J. Econ. Entomol. 85(6): 2258-2262
- Coudriet, D.L., N. Prabhaker, and D.E. Meyerdirk (1985)** Sweetpotato whitefly (Homoptera: Aleyrodidae): Effects of neem-seed extract on oviposition and immature stages. Environ. Entomol. 14: 776-779



- Cranshaw, W. (1988)** Western flower thrips. Colorado State Univ. Coop. Ext. Greenhouse Insect Pest Manage. Sheet No. 3
- Cravedi, P and F. Molinari (1984)** Tisanotteri dannosi alle nettarine. Infomatore fitopatologica 34 (10): 12-16
- Cravedi, P, F. Molinari, and G. Spada (1983)** Controllo del *Taeniothrips meridionalis* Preissn. (Thysanoptera: Terebrantia: Thripidae) dannoso alle nettarine. Redia 66: 37-46
- Doerderlain, T.A. and R.W. Sites (1993)** Host Plant Preferences of *Frankliniella occidentalis* and *Thrips tabaci* (Thysanoptera:Thripidae) for onions and associated weeds in the Southern High Plains. J. Econ. Entomol. 86(6): 1706-1713
- Edelson, J.V. (1985)** A sampling method for estimating absolute numbers of thrips on onions. The Southwest Ent. 10: 103-106
- Felland, C.M. and W.C. Kleiner (1992)** Silvering injury caused by western flower thrips to peaches and nectarines in Adams County, Pennsylvania. Proc. 67th Cumberland-Shanandoah Fruit Workers Conference.
- Felland, C.M., D.A.J. Teulon, L.A. Hull, W.C. Kleiner, and D.K. Polk (1993a)** Western flower thrips on Peach and Nectarine. Proc. Penn. Sta. Fruit News 73(4): 50-55
- Felland, C.M., D.A.J. Teulon, L.A. Hull, and D.K. Polk (1993b)** Distribution and management of thrips (Thysanoptera:Thripidae) on nectarine in the Mid-Atlantic Region. J. Econ. Entomol. 88(4): 1004-1011
- Felland, C.M., L.A. Hull, D.A.J. Teulon, and E.A. Cameron (1993c)** Overwintering of western flower thrips (Thysanoptera: Thripidae) in Pennsylvania. Can. Ent. 125: 991-973
- Felland, C.M., L.A. Hull, and W.C. Kleiner (1993d)** Management of thrips in Pennsylvania peach and nectarine. Proc. 69th Annual Cumberland-Shenandoah FruitWorkers Conference.

**Felland, C.M., D.A.J. Teulon, L.A. Hull, and D.K. Polk (1995)** Distribution and management of thrips (Thysanoptera: Thripidae) on nectarine in the mid-Atlantic region. J. Econ. Entomol. 88: 1004-1011

**Fournier, F., G. Boivin, and R.K. Stewart (1995)** Effect of *Thrips tabaci* (Thysanoptera: Thripidae) on yellow onion yields and economic thresholds for its management. J. Econ. Entomol. 88(5): 1401-1407

**Gerling, D. and A.R. Horowitz (1984)** Yellow traps for evaluating the population levels and dispersion patterns of *Bemisia tabaci* (Gennadius) (Homoptera: Aleyrodidae). Ann. Entomol. Soc. Am. 77: 753-759

**German, T.L., D.E. Ullman, and J.W. Moyer (1992)** Tospoviruses: diagnosis, molecular biology, phylogeny, and vector relationships. Annu. Rev. Phytopathol. 30: 315-348

**Gillespie, D.R. (1989)** Biological control of thrips (Thysanoptera: Thripidae) on greenhouse cucumber by *Amblyseius cucumeris*. Entomophaga 34(2):185-192

**Gillespie, D.R. and R.S. Vernon (1990)** Trap catch of western flower thrips (Thysanoptera: Thripidae) as affected by color and height of sticky traps in mature greenhouse cucumber crops. J. Econ. Entomol. 83: 971-975

**Gillespie, D.R. and D.J.M. Quiring (1993)** Extending seasonal limits on biological control. IOBC/WPRS 16(2): 43-45

**Grasselly, D. G. Perron, E. Navarro, and E. Delnord (1993)** Thrips du pecher et du nectarinier *Frankliniella occidentalis* observe en verger dans le sud de la France. Infos-Ctifl 90: 25-30

**Greenough, D.R. (1985)** Aluminium-surfaced mulch and disease resistance: approaches to the control of tomato spotted wilt virus in solanaceous crops. M.Sc. Thesis, Louisiana State University.

**Gupta, R. and N.K. Sharma (1993)** A study of the nematocidal activity of allicin- an active principle in garlic, *Allium sativum* L., against root knot nematode, *Meloidogyne incognita* (Kofoid and White, 1919) Chitwood, 1949. Int. J. Pest Mgmt. 39(4): 390-392

**Gurusubramanian, G. and S.S. Krishna (1996)** The effects of exposing eggs of four cotton insect pests to volatiles of *Allium sativum* (Liliaceae). Bull. Ent. Res. 86: 29-31

**Hall, R.A. (1981)** *Verticillium lecanii* as a microbial insecticide against aphids and scales. In Microbial Control of Plant Pests and Diseases. H.D. Burges (ed.). London Academic Press. pp 483-498

**Hall, D.G., C.C. Childers, and J.E. Eger (1991)** Estimating citrus rust mite (Acari: Eriophyidae) levels on fruit in individual citrus trees. Environ. Entomol. 20: 382-390

**Harcourt, D.G. (1965)** Spatial pattern of the cabbage looper, *Trichoplusia ni*, on crucifers. Ann. Entomol. Soc. Am. 58: 88-94

**Heidger, C. and W. Nentwig (1989)** Augmentation of beneficial arthropods by strip-management. 3. Artificial introduction of a spider species which preys on wheat pest species. Entomophaga 34(4): 511-522

**Hennebury, T.H., F.F. Smith, and D. Shriver (1974)** Flower thrips in outdoor rose fields and an improved method of extracting thrips from rose flowers. J. Econ. Entomol. 57: 410-412

**Heyde, J, v.D, R.C. Saxena, and H. Schmutterer (1984)** Neem oil and neem extracts as potential insecticides for control of hemipterous rice pests, pp.377-390, in H.Schmutterer and K.R.S. Ascher (eds.). Natural Pesticides from the Neem tree (*Azadirachta indica* A. Juss.) and other Tropical Plants. Proceedings, 2nd International Neem Conference, Rauischholzhausen, Germany, 1983.

**Higgins, C. (1992)** Western flower thrips (Thysanoptera: Thripidae) in greenhouses: Population dynamics, distribution on plants and associations with predators. J. Econ. Entomol. 85(5): 1891-1903

- Higgins, C.J. and J.H. Myers (1992)** Sex ratio patterns and population dynamics of western flower thrips (Thysanoptera: Thripidae). *Environ. Entomol.* 21(2):322-330
- Hubscher, T.L. (1983)** An investigation into the relationship between western flower thrips damage and orchard floor management in British Columbia apple orchards. MPM paper, Simon Fraser University.
- Immaraju, J.A., T.D. Paine, J.A. Bethke, K.A. Robb, and J.P. Newman (1992)** Western flower thrips (Thysanoptera:Thripidae) resistance to insecticides in coastal California greenhouses, *J. Econ. Entomol.* 85(1): 9-14
- Irwin, M.E. and K.V. Yeargan (1980)** Sampling phytophagous thrips on soybean. pp 283-304 in Kogan, M. (Ed.), *Sampling Methods in Soybean Entomology*. Springer Verlag, New York, 587 pp.
- Irwin, M.E., K.V. Yeargan, and N.L. Marson (1979)** Spatial and seasonal patterns of phytophagous thrips in soybean fields with comments on sampling techniques. *Environ. Ent.* 8: 131-140
- Isman, M.B., O. Koul, A. Luczynski and J. Kaminski (1990)** Insecticidal and antifeedant bioactivities of neem oils and their relationship to azadirachtin content. *J. Agric. Food Chem.* 38: 1406-1411
- Iwao, S. (1968)** A new regression method for analyzing the aggregation pattern of animal populations. *Res. Popul. Ecol. Kyoto Univ.* 10: 1-20
- Jensen, F. (1973)** Flower thrips damage to table grapes in San Joaquin Valley: 1) timing of halo spotting by flower thrips on table grapes. *Calif. Agric.* 27(10): 6-8
- Jones, T (1954)** The external morphology of *Chirothrips hamatus* (Trybom) (Thysanoptera). *Trans. R. Ent. Soc. Lond.* 105: 163-187
- Karandinos, M.G. (1976)** Optimum sample size and comments on some published formulae. *Bull. Ent. Soc. Am.* 22: 417-421

- Kawai, A. and C. Kitamura (1987)** Studies on population ecology of *Thrips palmi* Karny. XV. Evaluation of effectiveness of control methods using a simulation model. Appl. Ent. & Zool. 22(3): 292-302
- Kirk, W.D. (1984a)** Ecologically selective coloured traps. Ecol. Entomol. 9: 35-41
- Kirk, W.D. (1984b)** Ecological studies on *Thrips imaginis* Bagnall (Thysanoptera) in flowers of *Echium plantagineus* L. in Australia. Aust. J. Zool. 9: 9-18
- Kirk, W.D. (1985)** Effect of some floral scents on host finding by thrips (Insecta: Thysanoptera). J. Chem. Ecol. 11: 35-43
- Kourmadas, A.L., T. Zestas, and L.C. Agyriou (1982)** Timing of spraying for control of thrips in nectarine trees. Annales de l'Institut Phytopathologique Benaki 13: 120-129
- Lacasa, A, M.C. Martinez, J. Torres, and J. Aliaga (1991)** Datos preliminares sobre *Frankliniella occidentalis* como plago de la nectarina y el melocotonero en el sureste Espanol. Fruticultura profesional 36: 39-46
- LaRue, J.H., J.E. Dibble, and G. Obenauf (1972)** Thrips in nectarines. Blue Anchor: 21-25
- Latimer, J.G. and R.D. Oetting (1994)** Brushing reduces thrips and aphid populations on some greenhouse-grown vegetable transplants. Hortsci. 29(11): 1279-1281
- Letourneau, D.K. and M.A. Altieri (1983)** Abundance patterns of a predator, *Orius tristicolor* (Hemiptera: Anthocoridae) and its prey, *Frankliniella occidentalis* (Thysanoptera: Thripidae): Habitat attraction in polycultures versus monocultures. Environ. Entomol. 12:1464-1469
- Lewis, T. (1959)** A comparison of water traps, cylindrical sticky traps and suction traps for sampling thysanopteran populations at different levels. Ent. Exp. Appl. 2: 204-215
- Lewis, T. (1973)** Thrips, their biology, ecology and economic importance. Academic, New York.

- Lewis, T. (1981)** Pest monitoring to aid insecticide use. Phil. trans. R. Soc. Lond., B295, 153-162
- Liu, T.X., R.D. Oetting, and G.D. Buntin (1994)** Temperature and diel catches of *Trialeurodes vaporariorum* and *Bemisia tabaci* (Homoptera, Aleyrodidae) adults on sticky traps in the greenhouse. J. Entomol. Sci. 29: 222-230
- Liu, T.X. and P.A. Stansly (1995)** Toxicity and repellency of some biorational insecticides to *Bemisia argentifolii* on tomato plants. Ent. Exp. Appl. 74: 137-143
- Lloyd, M. (1967)** "Mean crowding". J. Anim. Ecol. 36:1-30
- Loomans, A.J.M., J.C. van Lenteren, M.G. Tommasini, S. Maini and J. Riudavets (1995)** Biological control of thrips pests. Wageningen Agricultural University Papers, Wageningen Agricultural University, 201pp.
- Lowery, D.T., M.B. Isman and N.L. Brard (1993)** Laboratory and field evaluation of Neem for the control of aphids (Homoptera: Aphididae). J. Econ. Entomol. 86(3): 864-870
- Lublinkhof, J. and D.E. Foster (1977)** Development and reproductive capacity of *Frankliniella occidentalis* (Thysanoptera: Thripidae) reared at three temperatures. J. Kans. Entomol. Soc. 50: 313-316
- Lynch, R.E. and A.M. Simmons (1993)**. Distribution of immatures and monitoring of adult sweetpotato whitefly, *Bemisia tabaci* (Gennadius) (Homoptera: Aleyrodidae), in peanut, *Arachis hypogea*. Environ. Entomol. 22: 375-380
- Madsen, H.F. and I.D. Jack (1966)** The relation of thrips to pansy spot on apples. Can. Ent. 98:903-908
- Matteson, N., I. Terry, A. Ascoli-Christensen, and C. Gilbert (1991)** Spectral efficiency of the western flower thrips, *Frankliniella occidentalis*. J. Insect Physiol. 38(6):453-459

- Matteson, N.A. and L.I. Terry (1992)** Response to color by male and female *Frankliniella occidentalis* during swarming and non-swarming behaviour. Entomol. exp. appl. 63: 187-201
- McBride, M.C. (1936)** A method of demonstrating rust hyphae and haustoria in unsectioned leaf tissue. Am. J. Bot. 23: 686-688
- Meidinger, D. and J. Pojar (1991)** Ecosystems of British Columbia. B.C. Ministry of Forests Publication.
- Mordue(Luntz), A.J. and A. Blackwell (1993)** Azadirachtin: an Update. J. Insect Physiol. 39(11): 903-924
- Morison, G.D. (1957)** A review of British glasshouse Thysanoptera. Trans. Royal Ent. Soc. London 109:467-534
- Moulton, D. (1948)** The genus *Frankliniella* Karny, with keys for the determination of species (Thysanoptera). Rev. de Ent. 19: 55-114
- Mound, L.A. (1967)** The British species of the genus *Thrips* Thysanoptera. Ent. Gaz. 18: 13-22
- Mound, L.A. (1971)** The feeding apparatus of thrips. Bull. Ent. Res. 60: 547-548
- Mound, L.A. and A.K. Walker (1982)** Terebrantia (Insecta: Thysanoptera). Fauna of New Zealand 1, 113pp.
- Mulligan, G.A. and P.G. Kevan (1973)** Color, brightness, and other floral characteristics attracting insects to the blossoms of some Canadian weeds. Can. J. Bot. 51: 1939-1952
- Naranjo, S.E., H.M. Flint, and T.J. Henneberry (1995)** Comparative analysis of selected sampling methods for adult *Bemisia tabaci* (Homoptera: Aleyrodidae) in cotton. J. Econ. Entomol. 88(6): 1666-1678

- Newsom, L.D., J.S. Roussel, and C.E. Smith (1953)** The tobacco thrips, its seasonal history and status as a cotton pest. La. Agric. Exp. Stn. Tech. Bull. 474
- Oliver, R.H.J. and C.R.B. Baker (1987)** *Frankliniella occidentalis* (Pergande) Thysanoptera:Thripidae. Ministry of Agriculture, Fisheries and Food, Harpenden Laboratory, England (unpubl. datasheet).
- Ota, A.K. (1968)** Comparison of three methods of extracting the flower thrips from rose flowers. J. Econ. Entomol. 61: 1754-1755
- Palumbo, J.C., A. Tonhasca, Jr., and D.N. Byrne (1995)** Evaluation of three sampling methods for estimating adult sweetpotato whitefly (Homoptera: Aleyrodidae) abundance on cantaloupes. J. Econ. Entomol. 85(5): 1393-1400
- Pedigo, L.P., G.L. Lentz, T.D. Stone, and D.F. Cox (1972)** Green cloverworm populations in Iowa soybean with special reference to sampling procedures. J. Econ. Entomol. 65: 414-421
- Pergande, T. (1895)** Observations of certain Thripidae. Insect Life 7: 392
- Pickett, C.H., L.T. Wilson, and D. Gonzalez (1988)** Population dynamics and within plant distribution of the western flower thrips (Thysanoptera: Thripidae), an early-season predator of spider mites infesting cotton. Environ. Entomol. 17(3):551-559
- Powell, C.C. and R.K. Lindquist (1992)** Ball Pest and Disease Manual. Geneva publishers.
- Prokopy, R.J. and E.D. Owens (1978)** Visual generalist vs. visual specialist phytophagous insects: host selection behaviour and application to management. Entomol. Exp. Appl. 24: 409-420
- Prokopy, R.J. and E.D. Owens (1983)** Visual detection of plants by herbivorous insects. Annu. Rev. Entomol. 28: 337-364



- Puche, H., J. Funderburk, and S. Olson (1993)** Captures of *Frankliniella* spp. (Thysanoptera: Thripidae) in tomatoes versus weather surrounding vegetation and placement of sticky cards. Entomol. (Trends Agric. Sci.) 1: 55-62
- Puche, H., R.D. Berger, and J.E. Funderburk (1995)** Population dynamics of *Frankliniella* species (Thysanoptera: Thripidae) thrips and progress of spotted wilt in tomato fields. Crop Protection 14(7): 577-583
- Puspitorini, R.D., G. Mudjoni, and M. Istianto (1992)** Pengaruh tumpang sari tanaman kubis dengan tanaman bawang putih terhadap populasi hama *Thrips tabaci* Lindeman, *Plutella xylostella* Dan, *Crocidolomia binotalis* Zeller. Agriviti 15(2): 34-38
- Rao, N.V., A.S. Reddy, and K.T. Rao (1991)** Monitoring of cotton whitefly, *Bemisia tabaci* with sticky traps. Madras Agric. J. 78(1-4): 1-7
- Sakimura, K (1962)** *Frankliniella occidentalis* (Thysanoptera: Thripidae), a vector of the tomato spotted wilt virus, with special reference to the color forms. Ann. Ent. Soc. Am. 55: 387-389
- Sakimura, K. (1963)** *Frankliniella fusca*, an additional vector for the tomato spotted wilt virus, with notes on *Thrips tabaci*, another vector. Phytopathology 53: 412-415
- Salguero Navas, V.E., J.E. Funderburk, R.J. Beshear, S.M. Obon, and T.P. Mack (1991a)** Seasonal patterns of *Frankliniella* spp. (Thysanoptera: Thripidae) in tomato flowers. J. Econ. Entomol. 84(6):1818-1822
- Salguero Navas, V.E., J.E. Funderburk, S.M. Olson and R.J. Beshear (1991b)** Damage to tomato fruit by the western flower thrips (Thysanoptera:Thripidae). J. Entomol. Sci. 26: 436-442
- Salguero Navas, V.E., J.E. Funderburk, T.P. Mack, R.J. Beshear, and S.M. Olson (1994)** Aggregation indices and sample size curves for binomial sampling of flower inhabiting *Frankliniella* species (Thysanoptera: Thripidae) on tomato. J. Econ. Entomol. 87(6): 1622-1626

- Salifu, A.B. and C.J. Hodgson (1987)** Dispersion patterns and sequential sampling plans for *Megalurothrips sjostedtii* (Trybom) (Thysanoptera: Thripidae) in cowpeas. Bull. Ent. Res. 77: 441-449
- Saxena , R.C., and Z.R. Khan (1985)** New bioactive products; Growth regulators, antifeedants, pheromones and other attractants. Mem. Sci. Fische Natur. Ser. V 11(2): 303-317
- Scheffler, I. and M. Dombrowski (1993)** Behavioural responses of *Blattella germanica* L. (Orthopt., Blattellidae) induced by repellent plant extracts. J. Appl. Ent. 115: 499-505
- Schmidt, M.E. and J.E. Frey (1995)** Monitoring of the western flower thrips *Frankliniella occidentalis* in greenhouses. Med. Fac. Lanbouww. Univ. Gent. 60(3a): 847-850
- Schmutterer, H. (1988)** Potential of azadirachtin-containing pesticides for integrated pest control in developing and industrialized countries. J. Insect Physiol. 34: 713-719
- Schmutterer, H. (1990)** Properties and potential of natural pesticides from the neem tree, *Azadirachta indica*. A. Res. Ent. 35: 271-297
- Scott, S.J., P.J. McLeod, F.W. Montgomery, and C.A. Hander (1989)** Influence of reflective mulch on incidence of thrips (Thysanoptera: Thripidae: Phlaeothripidae) in staked tomatoes. J. Entomol. Sci. 24(4):422-427
- Sharaf, N.S. (1982)** Determination of the proper height, direction, position, and distance of a yellow sticky trap for monitoring adult sweetpotato whitefly populations, *Bemisia tabaci* Genn. (Homoptera: Aleyrodidae). Disarat 9: 169-182
- Shelton, A.M., J.P. Nyrop, R.C. North, C. Petzoldt, and R. Foster (1987)** Development and use of a dynamic sequential sampling program for onion thrips, *Thrips tabaci* (Thysanoptera: Thripidae), on onions. J. Econ. Entomol. 80(5): 1051-1056

- Shelton, A.M. and R.C. North (1986)** Species composition and phenology of Thysanoptera within field crops adjacent to cabbage fields. *Environ. Entomol.* 15L 513-519
- Shipp, J.L. and G.H. Whitfield (1991)** Functional response of the predatory mite, *Amblyseius cucumeris* (Acari: Phytoseiidae), on western flower thrips, *Frankliniella occidentalis* (Thysanoptera: Thripidae). *Environ. Entomol.* 20(2):694-699
- Shipp, J.L. and N. Zariffa (1991)** Spatial patterns of and Sampling methods for Western Flower thrips (Thysanoptera: Thripidae) on greenhouse sweet pepper. *Can. Ent.* 123: 989-1000
- Sites, R.W., W.S. Chambers, and B.J. Nichols (1992)** Diel periodicity of thrips (Thysanoptera:Thripidae) dispersion and the occurrence of *Frankliniella williamsi* on onions. *J. Econ. Entomol.* 85(1): 100-105
- Southwood, T.R.E. (1978)** Ecological methods with particular reference to the study of insect populations. 2nd ed., 524 pp. London, Chapman & Hall.
- Stannard, L.J. (1968)** The thrips, or Thysanoptera, of Illinois. *Bull. Ill. Sta. Nat. Hist. Surv.* 29: 215-552
- Steiner, M.Y. (1990)** Determining population characteristics and sampling procedures for the western flower thrips (Thysanoptera:Thripidae) and the predatory mite, *Amblyseius cucumeris* (Acari: Phytoseiidae) on greenhouse cucumber. *Environ. Entomol.* 19: 1605-1613
- Stewart, J.W., C. Cole, and P.Lumms (1989)** Winter survey of thrips (Thysanoptera: Thripidae) from certain suspected and confirmed hosts of tomato spotted wilt virus in South Texas. *J. Entomol. Sci.* 24(3):392-401
- Tanigoshi, L.K. and D.S. Moreno (1981)** Traps for monitoring populations of the citrus aphid, *Scirtothrips citri* (Thysanoptera: Thripidae). *Can. Ent.* 113: 9-12
- Taylor, L.R. (1961)** Aggregation, variance and the mean. *Nature, Lond.* 189: 732-735

- Taylor, L.R. (1962)** The efficiency of cylindrical sticky traps and suspended nets. *Ann. Appl. Biol.* 50:681-685
- Taylor, L.R. (1963)** Analysis of the effect of temperature on insects in flight. *J. Anim. Ecol.* 32: 99-117
- Terry, L.I. (1991)** *Frankliniella occidentalis* (Thysanoptera: Thripidae) oviposition in apple buds: the role of bloom state, blossom phenology, and population density. *Environ. Entomol.* 20(6):1568-1576
- Terry, L.I. and G. DeGrandi-Hoffman (1988)** Monitoring western flower thrips (Thysanoptera: Thripidae) in "Granny Smith" apple blossom clusters. *Can. Ent.* 120:1003-1016
- Teulon, D.A.J. (1988)** Pest management of the New Zealand flower thrips *Thrips obscuratus* (Crawford) (Thysanoptera: Thripidae) on stonefruit in Canterbury, New Zealand. Ph.D. thesis, Lincoln College, University of Canterbury, New Zealand. 221pp. (& addendum).
- Teulon, D.A.J. and D.R. Penman (1987)** Thrips control on stonefruit at flowering in Canterbury. *Proceedings of the 40th New Zealand weed and pest control conference:* 262-266
- Teulon, D.A. and D.R. Penman (1991)** Effects of temperature and diet on oviposition rate and development time of the New Zealand Flower thrips (*Thrips obscuratus*). *Ent. Exp. App.* 60(2): 143-155
- Teulon, D.A. and D.R. Penman (1992)** Colour preferences of New Zealand thrips (Terebrantia: Thysanoptera). *N. Zeal. Entomol.* 15: 8-13
- Teulon, D.A., D.R. Penman, and P.J. Ramakers (1993)** Volatile chemical for thrips (Thysanoptera: Thripidae) host-finding and applications for thrips pest management. *J. Econ. Entomol.* 85(5): 1405-1415
- Teulon, D.A. and D.R. Penman (1996)** Thrips on ripe stonefruit in New Zealand, *J. Econ. Entomol.* 89(3): 722-734

- Thompson, W.R. (1950)** A Catalogue of the Parasites and Predators of Insect Pests. Section 1. Part 2. Parasites of the Neuroptera, Odonata, Orthoptera, Psocoptera, Siphonaptera and Thysanoptera. Commonwealth Agric, Bur. Ottawa 35pp
- Trichilo, P.J. and T.F. Leigh (1988)** Influence of resource quality on the reproductive fitness of flower thrips (Thysanoptera: Thripidae). Ann. Entomol. Soc. Am. 81: 64-70
- Varadason, S. and T.N. Anathakrishnan (1982)** Biological studies on some fall-thrips. Proc. Ind. Nat. Acad. Sci. B48 1: 35-43
- Venables, E.P. (1925)** Pansy spot on apple (a peculiar form of thrips injury). Proc. Ent. Soc. B.C., 22:9-12
- Vernon, R.S. and D.R. Gillespie (1990)** Spectral responsiveness of *Frankliniella occidentalis* (Thysanoptera:Thripidae) determined by trap catches in greenhouses. Environ. Entomol. 19: 1229-1241
- Vernon, R.S. and D.R. Gillespie (1995)** Influence of trap shape, size and background colour on catches of *Frankliniella occidentalis* (Thysanoptera: Thripidae) in a cucumber greenhouse. J. Econ. Entomol. 88(2): 288-293
- Walker, W.F. (1974)** Responses of selected Thysanoptera to colored surfaces. Environ. Entomol. 3: 295-304
- Wardle, R.A. and R. Simpson (1927)** The biology of Thysanoptera with reference to the cotton plant. 3. The relation between feeding habits and plant lesions. Ann. Appl. Biol. 14: 513-528
- Watts, J.G. (1936)** A study of the biology of the flower thrips *Frankliniella tritici* (Fitch) with special reference to cotton. S. Carol. agr. exp. ste. Bull. 306: 1-46
- Wellington, W.G. (1983)** Biometeorology of dispersal. Bull. Ent. Soc. Am. 29(3): 24-29

- Wellington, W.G. and R.M. Trimble (1984)** "Weather" in Ecological Entomology, eds. Huffaker, C.B. and R.L. Rabb. New York, Wiley. pp 399-425
- Wilkinson, L (1990)** SYSTAT: The system for statistics. Systat, Evanston, IL.
- Wilson, T.H. and T.A. Cooley (1972)** Planidium and an entomophilic nematode associated with the western flower thrips. Ann. Ent. Soc. Am. 65(2);399-401
- Yonce, C.E., R.J. Beshear, J.A. Payne and D.L. Horton (1990a)** Population distribution of flower thrips and the western flower thrips (Thysanoptera: Thripidae) in nectarines and their relative association with injury to fruit in the southeastern United States. J. Entomol. Sci. 25(3): 427-438
- Yonce, C.E., J.A. Payne, R.J. Beshear, and D.L. Horton (1990b)** Thrips (Thysanoptera: Thripidae) associated with unsprayed and sprayed peaches in Georgia. J. Econ. Entomol. 83(2): 511-518
- Yokoyama, V.Y. (1977)** *Frankliniella occidentalis* and scars on table grapes. Environ. Entomol. 6(1): 25-30
- Yudin, L.S., J.J. Cho, and W.C. Mitchell (1986)** Host range of western flower thrips, *Frankliniella occidentalis* (Thysanoptera: Thripidae) with special reference to *Leucaena glauca*.
- Yudin, L.S., W.C. Mitchell, and J.J. Cho (1987)** Color preferences of thrips (Thysanoptera:Thripidae) with reference to aphids (Homoptera: Aphididae) and leafminers in Hawaiian lettuce farms. J. Econ. Entomol. 80:51-55
- Yudin, L.S., B.E. Tabashnik, J.J. Cho, and W.C. Mitchell (1988)** Colonization of weeds and lettuce by thrips (Thysanoptera: Thripidae). Environ. Entomol. 17:522-526
- Yudin, L.S., Tabashnik, B.E., Mitchell, W.C., and Cho, J.J. (1991)** Effect of mechanical barriers on distribution of thrips (Thysanoptera: Thripidae) in lettuce. J. Econ. Entomol 84(1):136-139

**Zar, J.H. (1984)** Biostatistical analysis, 2nd ed. Prentice-Hall, Englewood Cliffs, N.J.

**zur Strassen, R. (1986)** *Frankliniella occidentalis* (Pergande, 1895) from North America as a new thysanopterous inhabitant of European greenhouses (German, English abstract), Nachrichtenbl. Deut. Pflanzenschutzd. 38: 86-88