THE ECOLOGY OF THE SOUTH AFRICAN CITRUS THRIPS *Scirtothrips aurantii* Faure AND ITS ECONOMIC IMPLICATIONS

THESIS

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ABSTRACT

The South African Citrus Thrips, *Scirtothrips aurantii* Faure (Thysanoptera: Thripidae) has been a serious pest of the citrus industry of Southern Africa for over 70 years. It is indigenous to Africa and has no recorded parasitoids and, in most citrus-growing regions, predators are not economically effective. Firstly, in this study, the general ecology of thrips was reviewed along with the recorded history of *S. aurantii* and its control. Host plant relationships of *S. aurantii* were then examined and wild hosts were not found to be important in promoting citrus thrips outbreaks in the orchard after flowering. In addition, *Scirtothrips dorsalis* Hood, which attacks citrus in Asia, was collected for the first time in Africa, but from Castor Oil plant. It is therefore a potential pest of citrus here. Notes on its appearance compared to that of *S. aurantii* were prepared.

Weekly sampling of *S. aurantii* adults was carried out from June 1984 to May 1990. Population fluctuations were then correlated with phenology of the citrus trees and the direct and indirect effects of weather. Temperature and rainfall were not found to be significantly directly correlated with thrips numbers recorded. However, the indirect effects of rainfall were important in promoting a large winter thrips population in certain years. Relatively high rainfall during March and April compared to that of the previous January and February stimulated atypical flushing of the citrus trees during autumn and the setting of out-of-season fruit. *S. aurantii* then exploited this unusual food source and high numbers were subsequently recorded in the following winter, as well as in spring. Thus the mild winter climate alone could not suppress thrips numbers at Letaba.

Dispersal / Emergence traps, which are used in the U.S.A. for the monitoring of *Scirtothrips citri*, were evaluated over 24 months, and were effective in recording population peaks of *S. aurantii*. The emergence rate of adults in relation to second instar larvae trapped was 43.7%. 35.7% of adults caught after emerging from the soil were males and 64.3 were females. In contrast, yellow traps had recorded 59.1% males and 40.9% females over the same period. The yellow traps were subsequently found to be biased towards male catches when young fruit and/or soft flush was present on the citrus trees. Relative inhibition of female flight activity during times of food abundance is known in other thrips species. During times of food scarcity, the bias in the yellow trap results disappeared.

At Letaba Estates, availability of food rather than the direct effects of weather was seen to be the most important factor in governing *S. aurantii* numbers. Because of the importance of soft flush in the promotion of *S. aurantii* population increase, it is recommended that more attention should be given to the control of thrips on, as well as conducting surveys for, this food source. As the climate at Letaba is so favourable for citrus thrips, even during winter, it is further recommended that trapping for *S. aurantii* is carried out throughout the year. Furthermore, males and females should be recorded separately in trapping results as the sex ratio gives an indication of the phenological state of the tree.

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1. INTRODUCTION

Thrips belong to the order Thysanoptera, and their closest relatives are considered to be the Hemiptera (Davies 1988). Although classified within the Exopterygota, thrips are similar to the Endopterygota in that their larval stages do not have wing buds. In addition, the two (or sometimes three) prepupal and pupal stages are non-feeding, relatively inactive stages and in this way similar to the true pupal stage of the Endopterygota (Imms 1948).

Most thrips are extremely small, as little as 0.5mm in length, although some tropical species may reach 14mm. There are more than 5000 known species, which are divided between the two Sub-orders, Tubulifera and Terebrantia (zur Strassen 1960).

Some thrips are predatory, for example *Scolothrips sexmaculatus* (Pergande) (Bailey 1939), but most are phytophagous. Some exploit cultivated crops in various parts of the world, and certain species are very serious pests e.g. *Thrips tabaci* Lindeman (Lewis 1973). Because individual thrips are short-lived, this allows several generations to be produced per year. They are therefore able to increase rapidly in numbers, particularly in tropical or sub-tropical climates. Despite this, in general plants suffering from thrips attack do not die but rather suffer superficial damage in the form of blemishes or retarded growth that may cause a reduced economic yield of crops.

A. THE ECOLOGY OF THRIPS.

Population dynamics of thrips

The magnitude of an animal (or plant) population varies within a year, and from year to year. This is the result of the action of various biotic factors (e.g. fecundity, the effect of parasites and predators, availability of food supply) and abiotic factors (e.g. the effects of weather) which ultimately determine the numbers of individuals.

Classically, mortality factors have been further divided into those that become increasingly effective as numbers in the population grow, known as density-dependent factors, and those which act independently of population numbers and which are known as density-independent factors (Smith 1935). A further category is that of negatively density-dependent factors whose proportionate influence decreases within a growing population. Density-dependent factors tend to stabilize a population around an equilibrium size whereas density independent and negatively density dependent factors do not.

i) Effects of Climate

Climate is generally thought of as a density-independent factor. It may sometimes have catastrophic effects, as for example when Harris et al. (1936) observed a marked reduction in numbers of *T. tabaci* on onions after three days of rain and hail. Similarly, many nymphs and adults of *Scirtothrips manihoti* (Bondar) can be killed by rain droplets (Samways 1979).

On the other hand, certain effects of climate may be beneficial to thrips. Drought-induced stress on a plant may cause an increase in the concentration of amino acids due to proteolysis

(Barnett & Naylor 1966), making the plant more nutritious for herbivores. Such stress is an important factor in causing outbreaks of psyllids in Australia (White 1969), and looper caterpillars in New Zealand (White 1974). Heavy thrips infestations are often associated with dry weather, as in the case of *Selenothrips rubrocinctus* (Giard) (Fennah 1965), and *Scirtothrips* species in general (Mound and Palmer 1981). The general association between thrips outbreaks and dry weather may therefore be a combination of drought-stress increasing the nutrient concentration of plants and the absence of the catastrophic action of rainstorms.

Certain thrips species react to extremes of temperature by hibernating or aestivating. For example, *Limothrips* spp. hibernate in bark and leaf litter (Lewis & Navas 1962). In hot dry climates, if desiccation is a danger in summer some species may aestivate within galls (Priesner 1964). In humid tropical or subtropical climates, thrips generally do not exhibit aestivation. This results in overlapping of generations with several different life stages present at any one time. Whether in a dry or humid hot climate, thrips may however try and reduce their exposure to high temperatures by remaining on the undersides of leaves (Fennah 1963).

Thrips have had a major influence on the development of theories on insect population regulation. *Thrips imaginis* Bagnall, an Australian species, was the subject of an extensive study by Davidson and Andrewartha (1948a and b). By measuring four abiotic factors involving temperature and rainfall, they were able to account for 78.4% of the observed population variance. They believed that weather, although acting mainly as a mortality factor independent of the thrips population density, could act as a density-dependent component of the environment in winter if thrips were forced to compete for a limited number of "safe sites", and unsuccessful individuals were subject to lethal weather conditions. However, climate had been excluded as a density-dependent factor in earlier work by (Nicholson 1933) because "Physical factors that are uninfluenced by the densities of animals cannot directly determine these densities".

A number of authors have re-examined Davidson and Andrewartha's original data. Andrewartha and Birch (1954) concluded that there was "no room" for another significant controlling factor (besides weather) and that population regulation in *T. imaginis* was therefore density-independent. In contrast, Smith's (1961) re-analysis of Davis and Andrewartha's original data showed strong evidence of density-dependence, although the regulating factor could not be identified. Again using the original data, Varley et al. (1973) found further evidence of density-dependence, perhaps supporting the original "safe sites" theory of Davidson and Andrewartha (1948a and b).

ii) Feeding and Dispersal

Thrips possess a unique form of sucking mouthparts. The feeding apparatus comprises two piercing maxillary stylets and a single functional left mandible (Mound 1971, Milne & Manicom 1978). A "punch and suck" feeding technique is employed whereby the mandible pierces a hole in the plant surface and the stylets are then inserted (Chisholm & Lewis 1984). These three components together enclose a central channel through which food is drawn (Heming 1978).

Phytophagous Thysanoptera show a number of diverse feeding strategies, nearly half the known species feeding on fungi (Palmer et al. 1989), whereas others are found in flowers, feeding either on pollen, nectar or the flower itself. Many exist purely on leaves. Species which are crop pests may attack leaves, flowers, fruit, vegetables or grain.

Thrips major Uzel and *Thrips fuscipennis* Haliday, pollinate their host plants in addition to feeding on the pollen grains (Kirk 1985). Provided that they do not destroy an excessive amount of pollen, the presence of such thrips may, on balance, be beneficial, and consequently the feeding activities of thrips are not always detrimental (Syed 1979). Other benefits to plants come from the activity of predatory thrips (Palmer & Mound 1989). For example, a number of species within the genus *Scolothrips* Hinds prey on phytophagous mites (Acari: Tetranychidae) (Priesner 1950), and *Aleurodothrips fasciapennis* (Franklin) is of benefit to citrus trees as it is an important predator of California red scale *Aonidiella aurantii* (Maskell) in China (Beattie 1986a).

Although the Thysanoptera are thought to be most closely related to the Hemiptera, they lack the long sucking mouthparts of the true bugs. They are therefore generally unable to penetrate into hosts through the tough cuticle of mature plant tissue, (although this is not always so). Consequently, many leaf-feeding thrips are limited to exploiting newly-formed soft vegetative growth (Reed 1970, Lewis 1973). Such tissues are usually transient because leaves harden rapidly, and thrips species which are associated with very young leaves tend to be particularly small and active (Palmer et al. 1989), examples including members of the genus *Scirtothrips*. In contrast larger, less active thrips tend to be associated with older leaves, as in the case of *S. rubrocinctus*, which mainly infests cashew and cacao leaves which have just hardened (Fennah 1955, 1963).

Whatever their food, thrips must undergo frequent dispersal in order to fully exploit temporary feeding and breeding sites. While the host-plant is in the process of a growth phase, a thrips feeding on young leaves will only need to make local (for example within-tree) flights, or walk, in order to discover fresh shoots. However, the end of the growth period will create an acute shortage of food. This will force thrips to desert the plants although, because adult emergence sometimes coincides with the time when leaves harden off, it cannot always be said with certainty which of the two stimulates peak flight activity (Lewis 1973). Individuals unable to disperse when the host plant matures or is no longer suitable for feeding upon will die, as in the case of larvae and flightless male adults of *Limothrips cerealium* Haliday (Lewis 1959a).

Flight is the main method of dispersal of thrips, although some wingless species are also capable of effective dispersal (Mound 1972). Johnson (1969) classified the migration or dispersal of insects into a number of categories. Many thrips species exhibit dispersal typical of Johnson's class Ib in that, after emerging, the adults fly off to find suitable feeding or breeding sites and do not return to their place of emergence. This type of dispersal is also typical of aphids (Hemiptera: Aphididae) and termites (Isoptera) in that the flight power of these insects is not great, the wind playing a significant role in transport. Not all thrips undertake class Ib dispersal. For example, *L. cerealium*, undergoes diapause during colder weather, the adults overwintering beneath bark. In spring these same individuals fly back to their feeding and breeding sites (Johnson's class IIIa).

On annual crops, thrips, whitefies (Hemiptera: Aleyrodidae) and aphids are similar in that they are often invasive pests on annual crops, and there is only a limited amount of time in which the pests can become established on the crop before harvesting occurs. For example, the sweet-potato whitefly, *Bemisia tabaci* (Gennadius) is polyphagous and movement occurs between cultivated and uncultivated host plants (Butler et al. 1986). In Britain, populations of *L. cerealium* shift from one crop to another according to the time of year (Lewis 1959a). Feeding on winter-sown cereals and grasses takes place in spring as the thrips emerge from hibernation. Cereals sown in spring are then fed upon in June and July when most egg-laying occurs. Finally, before entering hibernation, wild grasses are utilized. In America, Wolfenbarger & Hibbs (1958) showed that serious infestations of *T. tabaci* on cabbages were the result of immigration from nearby alfalfa and winter wheat.

One aspect of crop damage typical of invasive pests is that of edge effects. Considerably higher pest numbers may be found on the periphery of crops, with consequently greater economic damage than in the centre, particularly when other hosts occur nearby. Edge-plants have been observed to be more highly infested with aphids than plants in the centre of a field (Lewis & Stephenson 1966). This is because edge-plants are encountered first by an immigrating pest, particularly when the insect flies low over the ground. The economic impact of thrips is however not exclusively as a result of the invasion of crops. For example, Harding (1961) found that damage to onions in Texas caused by (mainly)

Frankliniella occidentalis (Pergande) was the result of a build-up of numbers within the field, and not because of mass immigration.

It is known that dispersal does not necessarily occur with equal readiness in all members of a population. This is clearly so in species such as *L. cerealium* which have wingless males, but in addition, the willingness of the females to fly varies with sexual development. Sexually immature females generally fly more readily than mature individuals (Lewis 1959a), and in the case of *Haplothrips faurei* Hood, the flight of gravid females is inhibited during times of food abundance (Putman 1965). In this way temporary food sources and breeding sites can be fully exploited.

iii) The role of natural enemies

Many species of thrips are attacked by parasites, parasitoids and predators. Parasitoids (Hymenoptera: Trichogrammatidae and Mymaridae) attack thrips eggs, and larvae are parasitized by certain species of Eulophidae (Lewis 1973). Parasitic nematodes are also known to infest thrips (Lysaght 1937). Examples of density-dependent regulation of phytophagous thrips populations by natural enemies are however few, one of these being the interaction between onion-feeding *T. tabaci* and *Thripoctenus brui* Vuillet (Hymenoptera: Eulophidae) in Japan (Sakimura 1937a). The parasitoid was subsequently imported into Hawaii (Sakimura 1937b) for control of the pest there.

Certain phytophagous thrips are attacked by generalist predators such as lacewings (Neuroptera: Chrysopidae) (Callan 1943), bugs (Hemiptera: Miridae and Anthocoridae) (Myers 1935, Hesse 1940, Priesner 1964) and predatory thrips (Thysanoptera: Phlaeothripidae) (Bedford 1943). An example of the successful biological control of a phytophagous thrips using a predatory mite is that given by Hansen (1988), where mass release of *Amblyseius barkeri* (Acari: Phytoseiidae) was used against cucumber-feeding *T. tabaci* in greenhouses.

B. THRIPS AS ECONOMIC PESTS.

1) GENERAL

Most of the thrips which are crop pests belong to the Sub-order Terebrantia. The damage caused to crops may purely be as a result of feeding. However, at least two economically important viruses (tomato spotted wilt and peanut yellow spot) are transmitted internally by thrips (Reddy & Wightman 1988, Amin 1980).

Particular thrips species may infest one or more crops over vast areas of the world and in some cases it is now difficult to tell with certainty the original range. An example of this is the "*Gladiolus*" thrips, *Thrips* (*Taeniothrips*) *simplex* Morison, which may have originated in southern Europe but which is now found all over the world wherever *Gladiolus* is grown (Lewis 1973). Sometimes however, it can be clearly seen when an exotic thrips species has invaded a country and is busy extending its range: *Thrips palmi* Karny, a pest of watermelons which was accidentally introduced into Hawaii is an example (Johnson 1986). A further example is the recent accidental introduction of the Western Flower Thrips *F. occidentalis* into South Africa where it is damaging ornamental flowers within greenhouses (Giliomee 1989).

The development of novel agricultural crops within a country may result in their colonisation by indigenous species and previously harmless insects may assume economic importance. For example in Alaska, *Taeniothrips orionis* Treherne became a pest of vegetables in newly-cleared areas (Washburn 1958). This is similar to the situation involving citrus which, native to South East Asia, is now the subject of attack by different species of thrips in various parts of the world where the crop has become established.

2) THRIPS PESTS OF CITRUS.

Ebeling (1950) gave details of thrips known to attack citrus at that time. A more recent review by Jeppson (1989) listed eleven species, including a number of thrips which are only sporadic pests on this crop.

Worldwide, the three most important thrips pests of citrus are members of the genus *Scirtothrips*: *S. aurantii* Faure, *S. citri* (Moulton), and *S. dorsalis*. These three species cause primarily a characteristic ring-shaped scar in the region of the calyx, although other blemish patterns may also be caused. Other thrips which feed on citrus tend only to feed (and cause blemishes) at the point of contact between two fruits or between a leaf and a fruit; the three *Scirtothrips* species may cause this type of damage as well. The next most important species is probably *Heliothrips haemorrhoidalis* (Bouché), an occasional pest in California and Australia (Beattie 1986b).

On citrus, the main economic damage from thrips is in the form of scarring of the fruit epidermis making it unsightly, although feeding takes place on both leaves and fruit. New vegetative growth may be stunted in the case of severe infestation. Damaged fruit is downgraded during the packing process or, if severely scarred, may only be considered suitable for processing for juice. As unblemished exportable fruit commands a far greater economic return for a citrus grower, the importance of thrips as pests on citrus is considerable.

In California, *S. citri* has been a serious economic pest for many decades (Horton 1918, Tanigoshi et al. 1981). This species has recently been collected in Florida (Flowers 1989), but is not yet considered a pest of the citrus industry there.

In Asia, *S. dorsalis* has only relatively recently become a pest of citrus in Japan (Mound & Palmer 1981, Hashimoto et al. 1984), and Burma (Anon 1985a). During the course of the present study, this thrips was collected on castor oil plant in South Africa (Gilbert 1986), but not from citrus fruit. There is to date very little information available concerning this species on citrus.

The South African Citrus Thrips *S. aurantii* is one of the key pests of citrus in southern Africa. Fruit remains vulnerable to damage for a long period of time, and control measures can be a significant proportion of the total pest control costs involved in producing export-quality fruit. This applies particularly within areas where *S. aurantii* is a chronic pest every year.

C. THE AUTECOLOGY OF S. AURANTII

Historical Review of Citrus in Southern Africa and Early Records of Citrus Thrips

Citrus can be divided into two main categories, sweet types and acid types. The sweet types (e.g. oranges, mandarins and grapefruit) originate from South-eastern China and the acid types (e.g. lemons, limes and citrons) from Southern India (Eshuys 1976). Citrus is therefore an exotic crop to South Africa. Trees were first introduced on the ship "Tulp", which arrived from St. Helena on the 11th of June 1654 (Webber 1925). These were planted in the garden of the first governor of the Dutch Colony, Jan Van Riebeeck. By 1656, further trees had been imported via St. Helena and also from India. In 1661, the first mention of mature fruit being picked was recorded. By this time, orange, lemon and pummelo trees had all been imported and planted.

The first reference to citrus thrips in South Africa can be attributed to C.P. Lounsbury, who noted damage from this insect soon after his arrival in South Africa at the end of the last century (Hall 1930). By the early 1920's, it was still being debated whether thrips control would always be worthwhile, due to the observed variation in severity of damage from year to year (Lounsbury 1923). Nevertheless, control measures similar to those used against *S. citri* in California were suggested. Two years later, citrus thrips in South Africa was considered to be a serious pest with widespread damage being reported by Webber (1925).

In Southern Rhodesia (now Zimbabwe), citrus thrips was of no importance during the first two decades of this century. In fact, Jack (1916), in an early work on citrus pests, made no mention of the insect at all. Up to 1924, thrips damage in that country was considered to be rare but the following year damage was far more widespread (Symes 1925). However, it was not until four years later that *S. aurantii* was fully described as a new species (Faure 1929), the first ecological studies on the species being published by Hall (1930). Nowadays, *S. aurantii* is known from Surinam, Chile and Peru (Jeppeson 1989), as well as being widespread in Africa. Although collected in Egypt on citrus (Priesner 1932), the species has never been recorded in nearby Israel where an extensive citrus industry exists.

Pest status in southern Africa

The severity of *S. aurantii* outbreaks varies considerably in different parts of South Africa. Bedford et al. (1985) summarized the pest status of *S. aurantii*. In the Transvaal Lowveld, Eastern Escarpment and Rustenburg areas, citrus thrips is a severe pest requiring multiple treatments every year. In Natal and the higher-lying areas of Transvaal such as Zebediela, incidence of thrips is not so high, but remains significant. In the Cape Province, citrus thrips is a minor pest and, in many orchards, control may not be necessary. The reason for this significant difference in pest status has never been fully explained, but may be related to the harsher winters in the Cape reducing populations to very low levels, and biological control by predacious mites (Grout & Richards 1992, see section on natural enemies below).

Life cycle

The life-cycle of *S. aurantii* is typical of a member of the Sub-order Terebrantia. Eggs, which take between six and 24 days to hatch on citrus depending on temperature, are deposited within the young leaves or fruit and are invisible to the naked eye (Bedford 1943).

On hatching, the thrips passes through two active feeding larval stages, the total duration of which is five days during October and November (Hall 1930). A further two moults give rise to the (non-feeding) prepupal and pupal stages which, during these same two months, last for a total of four days, after which the adult emerges. Opinions have differed as to the site of pupation. Early work on *S. aurantii* indicated that the prepupal and pupal stages occurred on the citrus tree, either beneath the calyx, or within the navel-end in the case of this particular cultivar (Hall 1930). In contrast, Bedford (1943) showed that pupation only very rarely occurred under the calyx. Fully-grown larvae were observed to drop from the tree into the leaf-litter mostly during late afternoon and evening.

Regarding the adult stage, Bedford (1943) recorded an average duration of 15 days in field cages although, in the laboratory, a few lived as long as 44 days. Wentzel et al. (1978) summarized the duration of the total life-cycle as 18 days in summer and 44 days in winter.

Citrus Thrips Population Biology

According to Wentzel et al. (1978), citrus thrips populations decline from the end of April until the beginning of August, due to cooler weather and diminishing food supply. Winter can therefore be thought of as the unfavourable season. Although cooler weather lengthens development time, diapause of *S. aurantii* does not occur (Hall 1930, Bedford 1943). A continuous overlapping of generations therefore results which complicates pest control.

In contrast, *S. citri*, in California, is subject to a winter of greater severity. According to early work on this species, the cold winter weather caused the death of all life-stages except eggs, which overwintered within the plant-tissue (Horton 1918, McGregor 1928). However, it was later found that during a mild winter a very few adults may survive (McGregor 1944). In spring, the surviving eggs hatch and give rise to discrete generations, at least at the beginning of the season (Anon 1984). The distinct generations greatly simplify pest control, and sprays are first directed against the larvae of the second generation as it is these which cause the primary damage to fruit.

Previous population studies of *S. aurantii* have only covered a single growing year of citrus in particular orchards (Bedford 1943, Stassen and Catling 1969, Samways et al. 1987). The extent to which the citrus thrips population varies from year to year in one location is therefore largely unknown. Bedford (1943) nonetheless recorded that less economic damage was caused by *S. aurantii* during the cooler and wetter of two seasons studied in different orchards.

Importance of Non-citrus Hosts

Faure (1929) listed over 70 host plants of *S. aurantii*. Although no special study of host plants other than citrus was made, Hall (1930) doubted that wild veld plants were of any significance in promoting outbreaks of *S. aurantii* on citrus. Similarly Samways et al. (1987) found that numbers of citrus thrips were much higher in orchards as compared to adjacent bush. In contrast to this, according to Bedford (1943) and Wentzel et al. (1978), where citrus is grown close to other host plants, fruit on the edge of orchards often shows greater thrips damage than towards the centre of orchards.

Natural Enemies

The use of predators and parasites of Thysanoptera has generally been of limited success in achieving economic control of pest species (Lewis 1973). As regards *S. aurantii*, there are no recorded parasitoids, although a number of predators are known. Insect predators of *S. aurantii* include *Orius thripoborus* Hesse (Hemiptera: Anthocoridae) (Hesse 1940), and a thrips *Haplothrips bedfordi* Jacot-Guillarmod (Bedford 1943), none of which are considered economically important.

Milne (1977) proposed that soil-inhabiting predatory mites, which are known to exist under citrus trees (Olivier 1968), might feed on the prepupal and pupal stages of *S.aurantii*, although no evidence was forthcoming. There are however two mites (Acari: Euseiidae) which are known to consume *S. aurantii* larvae on the citrus canopy, *Euseius citri* Van der Merwe & Ryke (Schwartz 1983) and *Euseius addaoensis addoensis* (McMurtry). There is mounting evidence that *E. a. addoensis* is exerting biological control of citrus thrips in the eastern Cape citrus-growing region of South Africa (Grout & Richards 1990, 1991a, 1992).

In California, canopy-inhabiting euseiid mites are considered by some authors to be of economic value as predators of *S. citri* (Tanigoshi & Griffiths 1982, Anon 1984), although the reduction in thrips damage is not always sufficient to prevent economic loss (Grout 1985). In contrast, certain results have indicated that these predatory mites are more important in controlling citrus red mite, *Panonychus citri* McGregor (Phillips 1984).

The lack of any significant biocontrol of *S. aurantii* in most citrus-growing regions of southern Africa is unfortunate for the industry because many other pests on this crop are the subject of successful biocontrol (Prinsloo 1984). Consequently, control of

S. aurantii has always relied solely on the application of pesticides. The use of certain of these pesticides can cause secondary outbreaks of other citrus pests as a result of the destruction of their normally effective natural enemies. For example, temephos (Abate), a highly effective thripsicide registered during the late 1960's caused outbreaks of California red scale *Aonidiella aurantii* (Maskell) (Bedford 1971). Parathion used for thrips control caused outbreaks of soft scales (Hemiptera: Coccidae) including citrus wax scale *Gascardia brevicauda* (Hall) (Cilliers 1978) and soft brown scale *Coccus hesperidum* L. (Annecke and Georgala 1978), as well as several species of mealybugs (Hemiptera: Pseudococcidae) (Cilliers and Bedford 1978). Although temephos is no longer used, and parathion only very rarely in certain regions, these examples illustrate the principle that citrus thrips control cannot be pursued regardless of the effect of such pesticides on other non-target species. As Georgala (1967) stated, the citrus thrips is truly "... a barrier to progress in citrus pest control".

Assessing populations of S.aurantii

In South Africa, assessment of *S.aurantii* numbers in orchards has traditionally been made by counting the proportion of infested fruit. Recently, the use of yellow sticky traps for catching flying adult citrus thrips has been implemented by growers (Samways et al. 1986). Previously, coloured sticky traps had been used to monitor various thrips species in England by Lewis (1959b), who found that the colour of the trapping surface strongly influenced the degree to which different thrips were caught. Coloured traps cannot therefore be used to compare the thrips community composition of an area or to compare absolute numbers of different species. It is interesting to note that Lewis (1973) stated "It is a puzzling fact that while many Homoptera such as species of psyllids, aphids and jassids feed on young pale-green plant tissue similar to that chosen by thrips, no thrips species are known to be markedly attracted to yellow whereas many species in these homopterous families are".

Beavers et al. (1971) investigated trap colour preferences of *S. citri*. White was shown to be more effective than yellow with green, red, black, and blue having little potential for monitoring citrus thrips with very low catches being recorded. Conversely, Moreno et al. (1984) suggested the use of fluorescent (Saturn) yellow to monitor *S.citri* as this colour gave the best results in their experiments.

In southern Africa *S. aurantii* and citrus psylla *Trioza erytreae* (Del Guercio) (Hemiptera: Triozidae) are known as key pests because of their considerable economic importance. During 1983 it became apparent that fluorescent yellow traps being used as part of a South African Co-operative Citrus Exchange research project to monitor citrus psylla, the vector of greening disease (McClean & Oberholzer 1965), were also effective in catching *S.aurantii* (Samways 1983, Personal communication). The ability to monitor two important pests with the same sampling method brought obvious advantages.

In South Africa, fluorescent (Saturn) yellow traps are now used quite extensively by citrus growers to monitor *S.aurantii* (Samways et al. 1986), and thresholds relating to economic damage have been established (Samways 1986, Samways et al. 1987). At Letaba Estates, where the present studies were carried out, both traditional scouting for infested fruit and trapping are now undertaken in order to provide as much information as possible about economically-damaging thrips populations.

Another type of trap that could be used to monitor *S. aurantii* is the so-called "Dispersal/Emergence" (or D/E) trap. This method relies upon pupation of *S. aurantii* taking place in the soil or leaf litter beneath the host plant. Traps of this type to monitor the dispersal of mature larvae of *S. citri* dropping to the ground to pupate and the emergence of adults from the leaf litter were first used by Reed & Rich (1975). They found that most larvae fell to the ground close to the citrus tree trunk and on the northern side of the tree. Tanigoshi & Moreno (1981) suggested an improved version of the trap but the principal of the trapping method remained the same.

Grout et al. (1986) presented evidence that a proportion of *S. citri* larvae pupated within the tree canopy, and the rest in the ground. Nevertheless, the D/E trap remains a useful tool in the monitoring of this species (I. Michael 1990 Personal communication). These traps have not been used commercially in southern Africa for monitoring *S. aurantii*. However, the observations of Bedford (1943) on the pupation site of *S. aurantii* indicate that this type of trap may well be of use here.

Chemical control of S. aurantii

Citrus pest control aims to produce blemish-free fruit because this is one of the measures of high quality (Carman 1989), although damage caused by certain insects and mites may just be cosmetic. This is especially relevant when considering control of *S. aurantii* which causes superficial rind blemishes.

The approach to citrus thrips control in the Transvaal, Natal, and Swaziland is preventative, i.e. a spray is applied at the end of the flowering period whether the presence of thrips has been confirmed or not. This is because high populations and subsequent economic damage can develop in a short time (Wentzel et al. 1978). As the fruit remains vulnerable for many weeks, a variable number of follow-up sprays are necessary, depending on the pesticide(s) chosen (Vermeulen et al. 1990).

The earliest control measures developed against *S. aurantii* involved two or three sprays of lime-sulphur, beginning at petal-fall (Faure 1929). Organophosphate pesticides, such as parathion which became available from 1950 onwards (Georgala 1967), controlled the complete spectrum of spring pests including California red scale *A. aurantii*, the bollworm *Heliothis armigera* Hubner (Lepidoptera: Noctuidae), *T. erytreae* and *S. aurantii*. Up to approximately 1960 a single full-cover spray was applied to control all these pests, including citrus thrips. However, due to increasing damage caused by thrips (or perhaps by stricter culling standards allowing less blemish on fruit than previously), more efficient control was required. This, along with bollworm control, could be achieved by lighter (known as "brush") sprays of parathion, also enabling the programme to be completed more quickly (Chamberlain 1979). Subsequently, during the early 1970's parathion became less and less effective in controlling red scale, due to the development of resistance to organophosphates (Georgala 1975). Ultimately, even repeated sprays of parathion failed to give control and it became uneconomic to continue such practices (Bedford 1990). Parathion has since been largely abandoned as a control material for any pest, although resistant red scale is not yet recorded in all parts of South Africa. The abandoning of this material stimulated the implementation of Integrated Pest Management in the Letaba and Letsitele districts of Transvaal and elsewhere, whereby more selective methods of pest control were adopted.

Today, a number of pesticides are registered for the control of *S. aurantii* in South Africa including isofenphos, triazophos, and a bait mixture of tartar emetic and sugar (Vermeulen et al. 1990). Interest is starting to be focussed on the possible resistance of citrus thrips to (particularly) organophosphate pesticides due to a number of field observations reporting failures in control, and variable susceptibility of different populations to parathion has been demonstrated under controlled conditions (Grout & Richards 1991b).

In California, resistance of *S. citri* to tartar emetic has been documented (Persing et al. 1942) and this chemical is no longer used for citrus thrips control there. Moreover, resistance to organophosphates such as dimethoate and other pesticides in current use has been demonstrated in detailed bioassays (Morse and Brawner 1986).

D. PHENOLOGY OF CITRUS AND DAMAGE CAUSED BY *S. aurantii*.

The growth cycle of citrus varies by a few weeks in different parts of southern Africa, reflecting mainly differences in latitude, the growing season in the Cape Province being three to four weeks later than in the Transvaal. However, few detailed studies have been made which include the timing of the flushing rhythm of citrus. Stassen & Catling (1969) recorded three major flush periods on citrus in Swaziland. Similarly Catling (1970), studying *T. erytreae* at Letaba Estates from January 1966 to March 1967, recorded three well-defined growth flushes; these occurring during August/September, December/January and February/March. These are the only records involving flushing of citrus at Letaba Estates prior to the present study and form the basis for the following account which outlines a typical growing-year in a navel orchard on the estates. In addition, the timing and pattern of citrus thrips damage is superimposed on this "typical" flushing cycle.

The "spring" growth flush usually starts to appear (in winter!) at the beginning of August and this forms an early source of food for citrus thrips. Flower buds are borne on most of the new shoots, and these open from the middle of August.

Flowering is completed by approximately the end of the third week in September in navel orange orchards. The point at which no further petals remain on the tree is commonly referred to as "100% petal-fall". Young fruitlets are then exposed on the tree. During petal-fall, the new leaves harden off so that, until the next growth flush, the only source of food on the tree for citrus thrips is the young fruit.

Like many species of thrips, *S. aurantii* seeks shelter in narrow crevices (exhibiting thigmotaxis) for much of it's life cycle. It is thought that this is why exposed very young fruit are not often attacked. A little later, thrips begin to infest the fruit after it has swelled slightly and a sheltered space forms beneath the sepals. It is very noticeable that, where petals remain stuck to a fruit instead of falling, thrips will exploit this shelter and cause damage earlier than on a fully-exposed fruit. Feeding beneath the calyx at this time results in what is known as "early-season" damage, a typically ring-shaped scar which, as a result of fruit growth during the season, emerges from beneath the sepals and may cover a large area on the mature orange (Hall 1930, Bedford 1943). Thrips may also feed in the shelter of petals or leaves if these touch the surface of the rind.

The second growth flush which Catling (1970) recorded in December provides another food source for *S. aurantii*. These new shoots are often heavily attacked. Thrips will again be forced to return to the fruit as the leaves harden. Damage can still be caused close to the stem-end around the calyx. However, in some cases as the fruit increases in size, the sepals may become closely adpressed to the rind leaving no place where thrips can hide and feed. If this is so then any further thrips damage (termed "late-season" marking) tends to take a number of different forms, to some extent depending upon whether the fruit are borne in bunches or not. Where one fruit hangs alone, late-season damage is confined to the sunny side of the fruit, either as "scribbling" or "browning" (also known as "russetting") (Roux 1937, Bedford 1943). In addition, *S. aurantii* may feed around the navel-end in the case of this cultivar. When disturbed, the thrips use the navel-end as a hiding place. Where more than one fruit hangs together, feeding can also occur around the point at which the fruit touch.

Opinions have varied concerning the length of time during which citrus fruit is susceptible to attack by *S. aurantii*. Hall (1930) suggested that damage in Rhodesia (now Zimbabwe) was caused between the 20th September and 30th November; and Bedford (1943) the period from 12 days after petal-fall to the end of December.

It should be remembered that there is an ever-increasing tendency for fruit quality standards to become stricter and an unblemished external appearance is an important factor in this. Smaller blemishes caused later in the season which previously would have not been considered as a culling factor are now assuming importance and there is evidence that the control of thrips may have to be extended beyond the calendar norms previously set (Kamburov 1991). In addition, fruit which are small are far more prone to attack than larger fruit. A fruit which grows quickly as a result of a good water supply and nutritional programme will be prone to attack over a shorter period of time than a fruit which receives a lesser amount of water and food. In other words, cultural practices have a great influence on the length of time that fruit is vulnerable to thrips attack.

The third growth flush, recorded by Catling (1970) as occurring in February and ending in March provides a fresh source of food. After the third flush has hardened citrus thrips numbers can be expected to decline. Subsequently, harvesting of navel oranges takes place in April. During the rest of autumn and throughout winter, the trees are irrigated sufficient only to prevent severe wilting. This is done in order to lightly stress the trees and induce as far as possible a state of dormancy which promotes the setting of a good crop the following spring (Reuther 1973). A three and a half month period of tree dormancy, lasting from April to mid-July was observed by Catling (1970).

E. AIMS OF THE STUDY

The aims of the study were:-

1. To examine the relationship between uncultivated hosts and citrus at Letaba. Host plants in addition to citrus were to be identified. In addition it was necessary to establish whether the serious thrips infestations which can occur on citrus in spring at Letaba result from mass immigration of adult *S. aurantii* from other hosts.
2. To record weather data and the timing of growth flushes of citrus at Letaba and relate these to the occurrence of *S.aurantii*.
3. To monitor the population of *S. aurantii* in a specific citrus orchard over a number of years using yellow traps.
4. To evaluate Dispersal / Emergence traps as a possible aid in the monitoring of citrus thrips in commercial orchards as is practiced in the U.S.A.
5. To compare the results obtained from the two different trapping methods, viz. yellow traps and Dispersal / Emergence traps.

2. LOCALITY, MATERIALS AND METHODS

Locality

Experimental work was carried out on Letaba Estates (figure 2.1), situated approximately 20 kilometres south-east of Tzaneen in the north-eastern Transvaal Lowveld, (map reference 30° 18'E 23° 52'S). The specific orchard used (plot 371 on section L) consisted of 200 mature Washington navel trees. It was surrounded by undisturbed bush and could therefore be easily omitted from commercial spraying operations (figure 2.2).

The estates are situated in the summer-rainfall region of South Africa. For the promotion of flowering of the orange trees, irrigation is therefore essential. In total, there are 1850 hectares of citrus plantings on the estate, with Washington navel and valencia late being the two main cultivars of orange grown.

As explained in the introduction, in common with the rest of the Letaba and Letsitele districts, Letaba Estates experienced severe problems in the late sixties and early seventies as a result of California red scale developing resistance to the parathion that was then in use (Georgala 1975). From the mid-1970's, a number of factors helped to bring about a recovery from what was a very serious situation. Firstly, pest control at Letaba changed radically with a move away from broad-spectrum organophosphates towards Integrated Pest Management with greater use of short residue pesticides. In addition, high-pressure rinsing of fruit in the packhouse mechanically removed red scale and helped to recover fruit which otherwise would have had to be

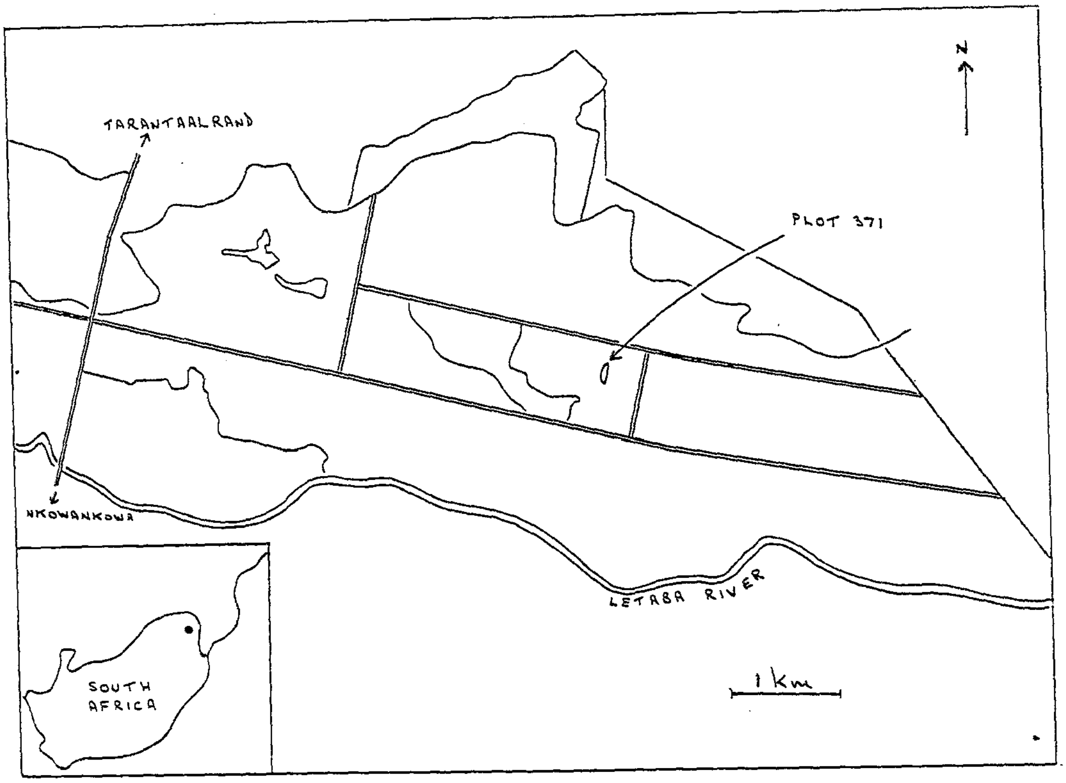


Figure 2.1. General diagram of Letaba Estates showing position of orchard (plot 371) in which experimental work was carried out.

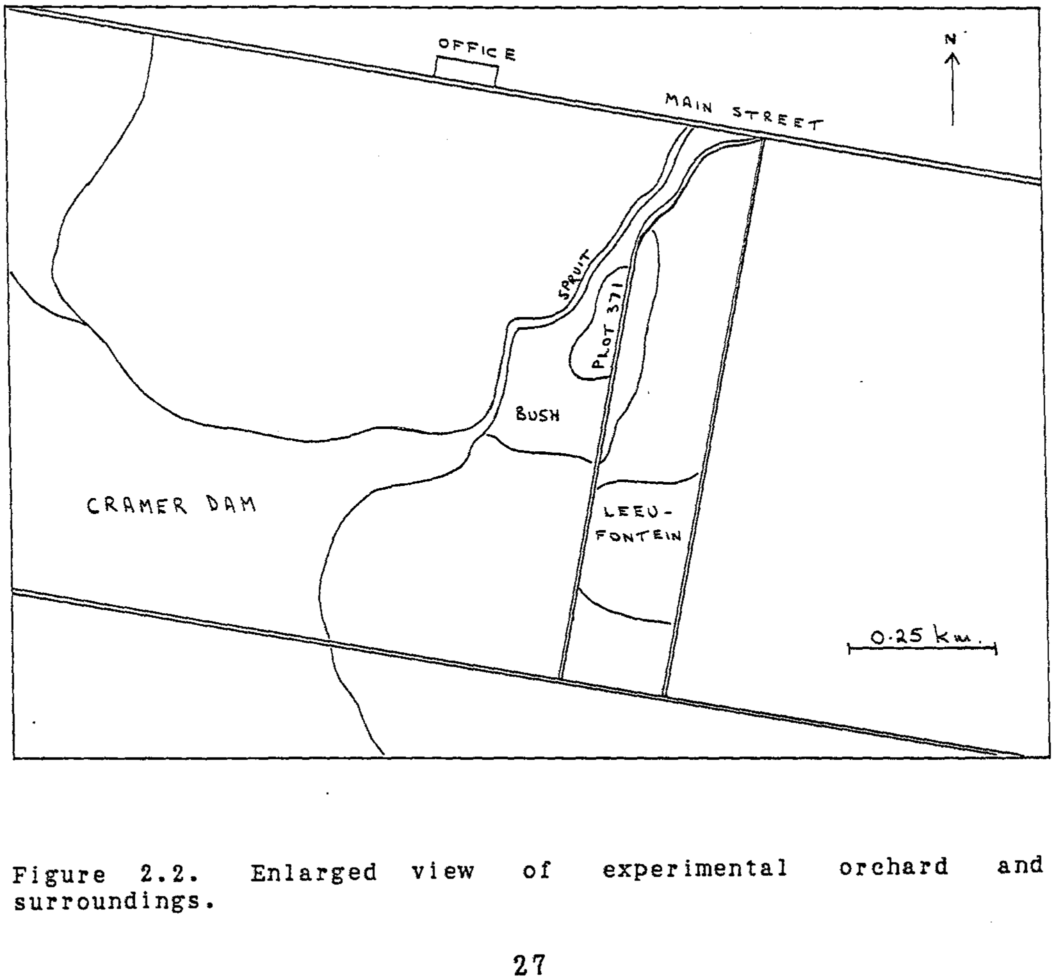


Figure 2.2. Enlarged view of experimental orchard and surroundings.

rejected (Bedford 1977, Honiball et al. 1979). Furthermore, experimental sprays of narrow-range miscible oils for red scale control carried out by S. Kamburov led to the implementation of a winter and summer spray programme by the estates entomologist F. Honiball, and reduced the use of organophosphate pesticides. This allowed the build-up and survival of parasitoids that aided in scale control (Bedford 1979).

Materials and methods

Weather Data.

Letaba Estates is equipped with a weather station, the data from which are submitted to the Citrus and Subtropical Fruit Research Institute, Nelspruit. Throughout the course of this study the rainfall and the maximum and minimum temperature were recorded on a daily basis.

Surveys for new growth

Citrus is a crop which exhibits fairly well-defined growth cycles. At certain times of the year, new shoots may be absent or so few that they are undetectable by a normal survey. During the study a weekly survey of the presence or absence of new growth points on ten trees was carried out. The occurrence of 100% petal-fall was also noted, this being the time at which control of citrus thrips on fruitlets traditionally begins.

Methods of assessing thrips populations.

A. Sampling of adult citrus thrips.

A method was required whereby consistent samples of thrips could be taken over a long period of time. Direct counts of infested foliage and fruit do not always give an accurate estimate because large numbers of thrips may occur per shoot or per fruit, which makes counting difficult. During hot weather, thrips movement is rapid, further compounding the problem of accurate counting. Surveys based on the number of thrips present on new shoots will automatically show nil if no new shoots can be found. This may give a very inaccurate picture as thrips tend to alternate between fruits and shoots depending on the relative palatability at any particular time. The problem therefore arises as to to which part of the tree to sample at which time.

In order to obtain a consistent sample of the population of *S.aurantii*, independent of whether the insects were on new leaves or fruit, and practical when thrips were at extreme densities, use was made of yellow sticky traps (Samways 1986). Each trap measured 25cm x 25cm and consisted of a self-adhesive fluorescent "Saturn" yellow plastic sheet overlain with an overhead transparency slide smeared with Reverant ᴿ and supported by a perspex or zinc plate. To prevent fading of the fluorescence as a result of direct exposure to the sun, traps were hung on the south side of the trees (Samways et al. 1986). Traps were placed at a height of two metres. Six traps were placed in the citrus orchard. These were positioned in two rows of three, with approximately 10 metres between rows and a similar distance between traps within a row. Counts of adult male and female citrus thrips were recorded separately on a weekly basis.

B. Sampling of mature larvae and emerging adults.

These two life-stages were sampled using D/E traps, similar to those used by Tanigoshi and Moreno (1981) for monitoring *S. citri*. Each trap consisted of a P.V.C. cylinder with an internal diameter of 190 mm and a height of 200 mm. The trapping surface was a square of clear perspex 220 mm x 220 mm x 2mm placed on top of the cylinder and covered on both sides by a transparent film of sticky Reverant ^{R}. In order to maximize efficiency of the traps, it was necessary to ascertain the best position for placement under the tree canopy. Traps were placed at four distances from the trunks of three experimental trees as done by Reed & Rich (1975). The traps were placed around the four cardinal compass points at 30cm, 60cm, 90cm and 120cm from the trunk making a total of 16 traps per tree. The traps were left in place for one week after which time the perspex squares were covered in Gladwrap^{R} and taken to the laboratory for examination. The experiment was run for three separate weeks during May and June 1986, at a time when the orchard was supporting a high thrips population. A total of nine tree replicates and 144 individual trap counts were undertaken.

Having established the best position for the traps in relation to the tree trunk, a long-term experiment was begun using four traps per tree in order to evaluate the usefulness of dispersal-emergence traps as an aid to monitoring orchard populations of *S. aurantii*.

Identification of thrips and specimen preparation.

Comparative samples of thrips from wild vegetation and citrus were obtained by beating branches showing new growth with a stick. This caused insects to be dislodged onto white paper placed beneath. Thrips were then collected with an aspirator and placed into 70% alcohol.

Permanent mounts of adults were made following the methods of Mound & Pitkin (1972). Some of these specimens remained uncleared to allow colour comparison between species. Others were fully cleared by macerating in sodium hydroxide so that setal patterns could be examined. Certain specimens were sent to Dr. R. zur Strassen of the Senckenberg Museum, Frankfurt, Germany for identification. As regards the larvae of thrips, these proved to be extremely delicate and only temporary mounts, made by clearing in 60% lactic acid for two to three days, were satisfactory.

Identification of alternative host plants

The identification of host plants of *S. aurantii* was a three-stage process. The first involved the collection and identification of adult citrus thrips on the plant. The second stage was to demonstrate that larvae could develop to maturity on the plant. The final stage was the identification of the plant.

Having identified adults of *S. aurantii* on a particular plant (see above) it was necessary to find out if the thrips was capable of completing its life cycle on the host. Adult insects are typically more polyphagous than larvae and, also being highly mobile, their presence alone on a plant is not a good host plant indicator. If the development of larvae to maturity on a

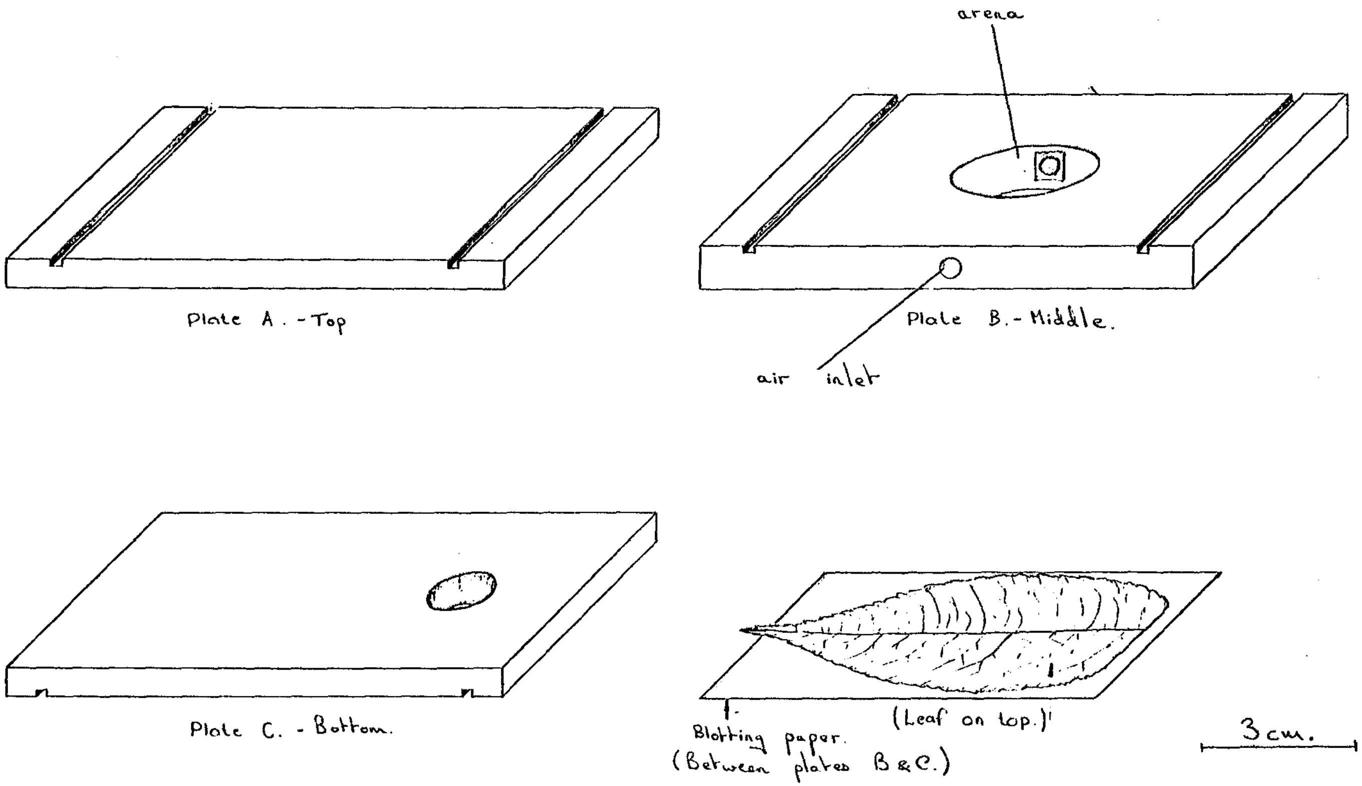


Figure 2.3. Components of perspex cage for containing thrips (modified from Tashiro 1967). Drawing by L. Hartwig.

particular plant could be demonstrated then it could be regarded as a true host bearing in mind that the prepupa and pupa of thrips are non-feeding stages. Second instar thrips larvae were therefore collected, from plants on which adult *S. aurantii* had been found, and confined within a "Tashiro" acrylic cage (Tashiro 1967, figure 2.3), containing host leaves as a larval substrate. The larvae pupated within the cage, and the identity of the emerging adults could be subsequently ascertained using the methods described previously. A particular plant species was therefore only recorded as a host of *S. aurantii* if an adult of this species developed from larvae collected on the plant.

Finally, in order to identify the host plant, herbarium specimens were then collected and sent to the Botanical Research Institute, Pretoria to confirm the identification.

3. A COMPARISON OF CITRUS THRIPS POPULATIONS IN AN ORCHARD AND AN ADJACENT SEMI-NATURAL HABITAT.

Introduction

Certain species of thrips are known to cause damage after invading crops *en masse*, for example *T. tabaci* (Gaines 1934). This is especially so if crops with different times of harvesting are grown close together. The cutting of a particular crop may cause an acute food shortage and force the thrips to fly to another uncut crop (Hightower & Martin 1956). On the other hand, Harding (1961) found that in the absence of harvesting of other crops, thrips damage on onions caused by (mainly) *F. occidentalis* was primarily as a result of a build-up of numbers by breeding within the crop and not invasion.

S. aurantii is polyphagous with over 70 host plant species having been recorded (Faure 1929). Opinions have varied as to the importance of non-citrus hosts as sources of thrips in orchards. Hall (1930) recorded host-plants in Southern Rhodesia (Zimbabwe) but doubted whether the number of thrips observed on them posed a danger to nearby orchards. More recently, Samways et al. (1987) came to the same conclusion after showing that population densities of *S. aurantii* were consistently lower in natural vegetation than on citrus in both the eastern Cape Province and eastern Transvaal.

During an examination of the relationship between thrips populations in citrus orchards and adjacent natural vegetation in the western Transvaal, Bedford (1943) found *Acacia* trees to be important alternative hosts. He found that fruit on citrus trees adjacent to acacias showed more thrips damage than fruit in the centre of orchards. Although this damage was caused in early November, it was postulated that migration of *S. aurantii* from natural bush onto citrus might sometimes occur as early as August and September and thus account for the presence of citrus thrips on fruit soon after blossoming.

In this study, the aims were:-

a) to identify alternate host plants of *S. aurantii* at Letaba.

b) to identify other thrips species which closely resemble *S. aurantii*, so as to eliminate confusion with them.

c) to determine whether the spring infestation of *S. aurantii* on citrus at Letaba is caused by thrips which have overwintered in the orchard, or results from immigration of adults from adjacent bush. The implications of these results for recommended control measures and monitoring procedures are discussed.

Materials and Methods

Studies were undertaken from September to December 1986 and 1987 in the study orchard. The surrounding vegetation contained thorn trees, (mainly the Whitethorn, *Acacia polyacantha* Willd. subsp. *campylacantha* (Hochst. ex A.Rich) Brenan), interspersed with smaller plant species including Sicklebush *Dichrostachys cinerea* (L.) Wight & Arn. subsp. *nyassana* (Taub.) Brenan, and Pride of the Cape *Bauhinia galpinii* N.E. Br.

Sampling and specimen identification

The collection and identification of thrips and their host plants was carried out using the methods described in chapter 2.

Trapping

In addition to the six yellow sticky traps placed in the citrus orchard as described in chapter 2, a further six traps were placed with a similar orientation and spacing in the undisturbed habitat. Counts of thrips were recorded weekly.

During preliminary sampling of adult thrips it became apparent that *Scirtothrips fulleri* Faure and *S. aurantii* were very similar in appearance. It was therefore decided to monitor the occurrence of both these species on the traps.

Results

Thrips species recorded

During this study, a total of 15 different species of Thysanoptera were collected and these are listed in Gilbert (1990). Three species were considered to resemble *S. aurantii* such that a danger of confusion might result when using yellow sticky traps to monitor thrips, namely *Thrips tenellus* Trybom, *S. fulleri* and *S. dorsalis*.

T. tenellus was often trapped in the citrus orchard during flowering time. A comparison of the appearance of this species and that of *S. aurantii* has been published by Samways et al. (1986). *S. fulleri*, at times numerous in samples and on traps, resembled *S. aurantii* the closest, and careful reference should be made to Faure (1929) in order to distinguish the two species. *S. dorsalis* was common in samples from *R. communis* but was trapped on very few occasions. Despite the fact that *S. dorsalis* attacks citrus in Asia (Mound and Palmer 1981), this cannot yet be confirmed in South Africa as this species was not present in samples taken from citrus fruit or foliage and was recorded only twice on traps within the orchard. It remains however a potential pest, and distinguishing characters of the larvae of *S. aurantii* and *S. dorsalis* are presented in chapter 4, where features of the adults are also reviewed.

Host plants of citrus thrips

In addition to citrus, the following seven wild host plants of *S. aurantii* supported both adults and larvae; *Acacia karroo* Hayne, *Acacia polyacantha* subsp. *campylacantha*, *Bauhinia galpinii*, *Caesalpinia pulcherrima* (L) Schwartz, *Dichrostachys cinerea* subsp. *nyassana*, *Mucuna coriacea* Bak. subsp. *irritans* (Burtt-Davy) Verdc., and *Ricinus communis*.

Comparison of citrus thrips numbers in the orchard and adjacent bush.

In 1986 and 1987, 100% petal-fall occurred by the end of the third week in September. In 1986, *S. aurantii* numbers built up rapidly within the orchard prior to 100% petal-fall (figure 3.1). In contrast, *S. aurantii* in the adjacent bush was first detected only during the third week in September and in very low numbers. Major differences in the two populations continued until the end of October. In 1987, the pattern was similar during September and October (figure 3.2). However, in contrast to 1986 during November and December *S. aurantii* numbers in the bush markedly exceeded those in the orchard. During 1986, *S. fulleri* was common in the bush and in October considerably outnumbered *S. aurantii* (figures 3.1 and 3.3), but was only found in insignificant numbers throughout 1987.

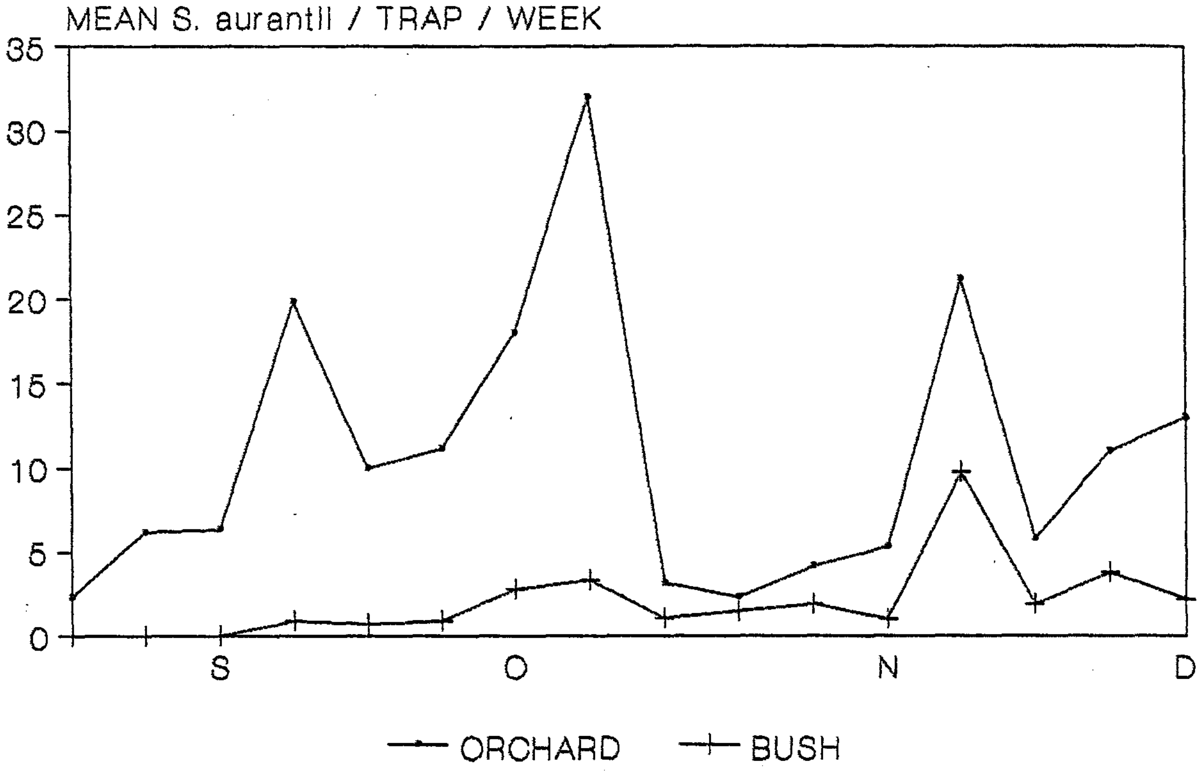


Figure 3.1. Weekly numbers of *S. aurantii* adults recorded on yellow traps in the citrus orchard and adjacent bush, September - December 1986.

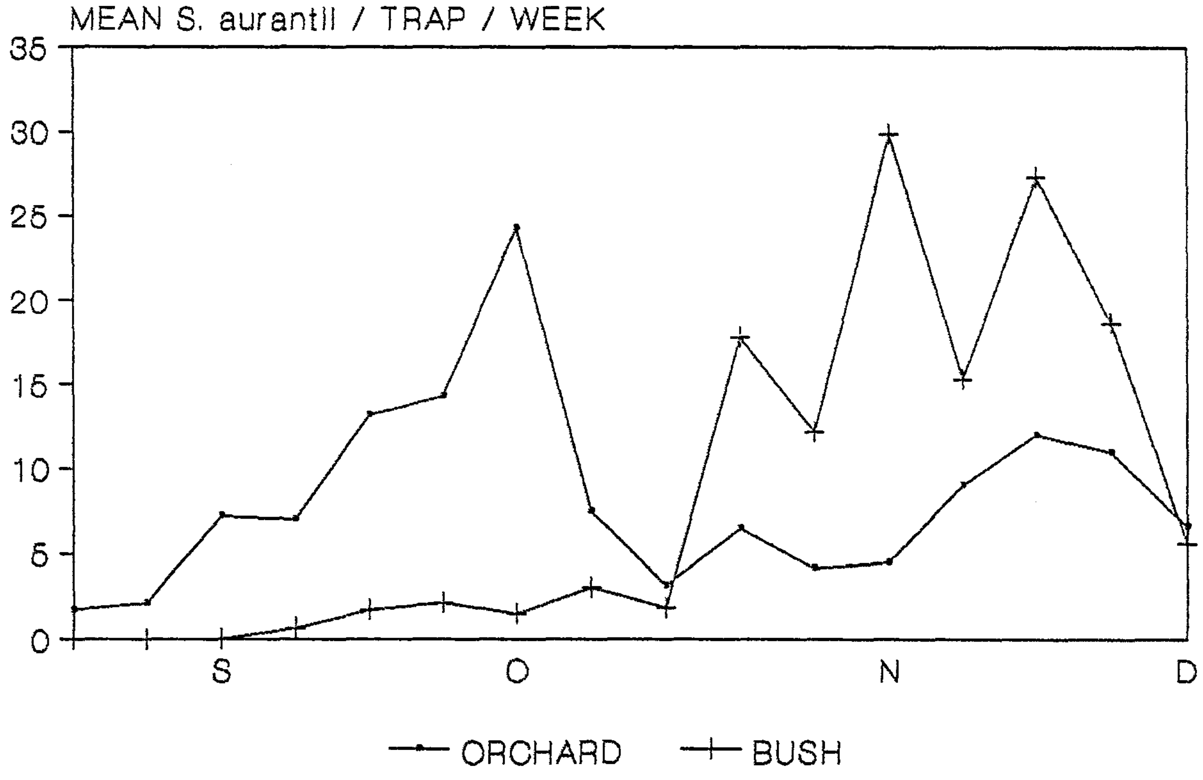


Figure 3.2. Weekly numbers of *S. aurantii* adults recorded on yellow traps in the citrus orchard and adjacent bush, September - December 1987.

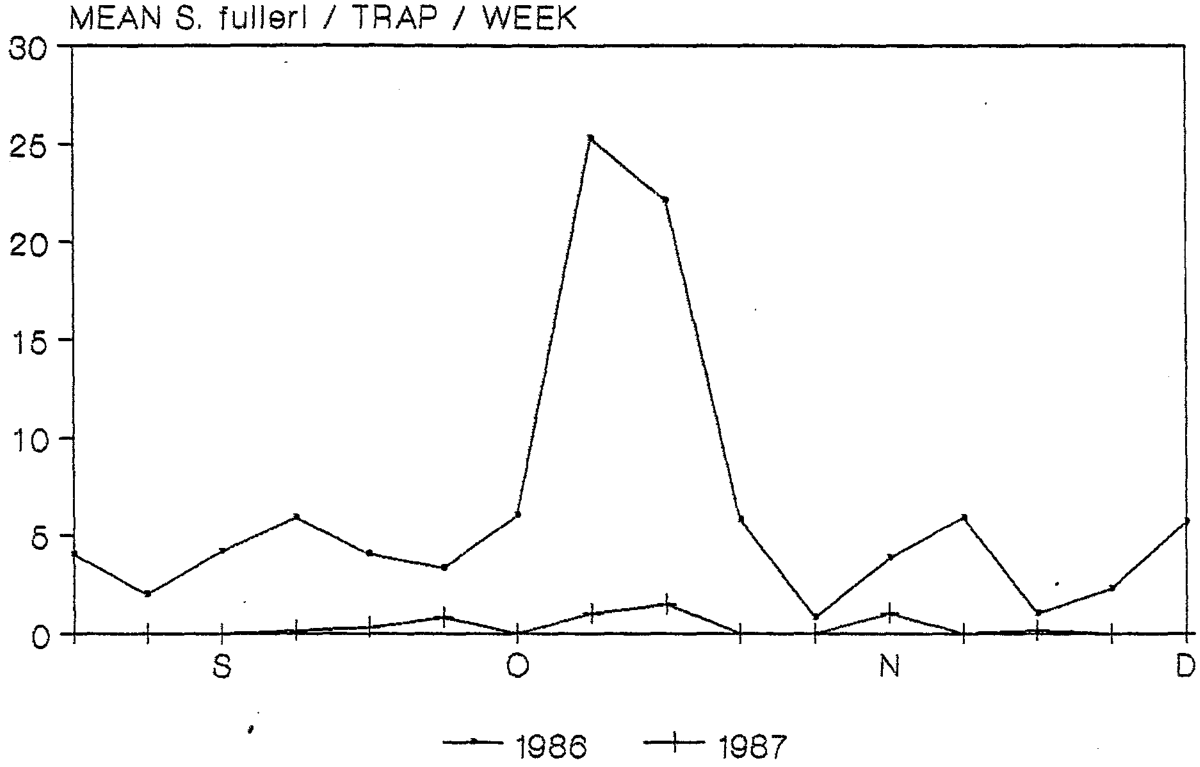


Figure 3.3. Weekly numbers of *S.fulleri* adults recorded on yellow traps in bush adjacent to the citrus orchard, September - December 1986 and 1987.

Discussion

Samways et al. (1986) set an economic threshold of nine *S. aurantii* caught per three traps per week; i.e. a mean of three thrips per trap. In the Transvaal, maintenance of catches in citrus orchards below this figure up to the third week in November, and below 20 thrips per three traps from then on until the end of December, was found to result in less than 1% of the fruit being unexportable because of thrips damage. Figures 3.1 and 3.2 show that at 100% petal-fall, (during the third week of September), the time when thrips control to protect fruit normally begins, numbers of *S. aurantii* in the orchard already exceeded the threshold by over 600% in 1986 and 200% in 1987. Thus severe damage can occur to young fruitlets very early in the season at Letaba if chemical sprays are not timed correctly.

The results show that host-plants in bush adjacent to citrus orchards did not support a large population of *S. aurantii* during September and October. The bush population was insignificant in comparison to that which developed within the orchard itself. This agrees with Samways et al. (1987) who found that citrus thrips numbers were consistently higher in citrus orchards, particularly during September and October.

Bedford (1943) found that citrus fruit on trees adjacent to bush showed more damage from thrips than that on trees towards the centre of the orchard. The initial thrips infestation in these orchards was low and two dustings with sulphur further reduced numbers of the pest, such that no damage occurred during September and October. However, during November *S. aurantii* numbers on citrus trees bordering bush began to increase and damage to fruit occurred. This was ascribed to thrips migrating from adjacent acacias whose leaves were hardening off making them unsuitable as a further food source for thrips. The theory was put forward that similar thrips migrations might occur as early as August or September and be responsible for the initial infestation which causes early damage to fruit. The results presented here, and those of Samways et al. (1987), show that this is not the case.

The results of 1987 do however show that, during November and December in certain years, larger numbers of citrus thrips may occur on nearby bush as compared to citrus. They may pose a threat to adjacent citrus, when the food quality of the natural bush declines, and would account for the results of Bedford (1943) at Rustenburg. The danger of bush populations of *S. aurantii* acting as sources of thrips late in the season was not evident in the results of Samways et al. (1987).

In order to promote flowering and fruit-set of navels, irrigation and fertilizer are applied during late June and new vegetative growth is usually visible at the end of July or at the beginning of August. This can immediately be used as a food source by citrus thrips which have overwintered in the orchard on out-of-season shoots and fruit. Letaba Estates is in the "summer-rainfall" area of South Africa, and the surrounding bush tends to be very dry with no new growth during July and August. Early in the season, conditions for *S. aurantii* population increase are therefore more favourable on citrus than in adjacent bush. Bearing in mind that a certain percentage of navel orange fruitlets can be at risk from thrips during the second week of September if uneven blossoming occurs, the extent of early damage will be related to the size of the pest population within the orchard and the effectiveness of any control measures. Later-flowering cultivars such as valencias will be at greater risk from immigration of citrus thrips from the bush because their fruit remain smaller and more vulnerable to scarring until later in the season.

As regards other thrips, *S. fulleri* was found to be the species most likely to be confused with *S. aurantii*. Although this thrips was rare within the orchard it was common on bush traps during September and October 1986. Citrus growers wishing to monitor thrips in adjacent bush, as an aid to pest management, would have to take care to avoid confusing these two species, especially as *S. fulleri* is of no economic importance. Scoring of *S. fulleri* as *S. aurantii* would erroneously increase the apparent importance of non-citrus hosts.

Growers have traditionally taken counts of infested fruit beginning at petal-fall to estimate the severity of a citrus thrips outbreak. As wild hosts are of no importance in early spring, trapping of citrus thrips within the orchard prior to, and during, blossoming will give advance warning of the level of infestation to be encountered before any damage to fruit can occur.

4. DISTINGUISHING FEATURES OF *S. aurantii* AND *S. dorsalis* AS AN AID TO IDENTIFICATION.

Introduction

S. aurantii is recorded from many different locations in Africa (Anon 1961), as well as from Surinam, Chile and Peru (Jeppeson 1989). *S. dorsalis* is widely distributed within Asia and Australasia (Anon 1986). Consequently their distributions have not previously been known to overlap.

The Castor oil plant, *Ricinus communis* Linnaeus, is recorded as a host plant of both *S. aurantii* (Hall 1930, Bedford 1943) and *S. dorsalis* (Hood 1919, Ananthakrishnan 1973). This plant grows wild at Letaba Estates, sometimes in close proximity to the citrus orchards. During this study, samples of adult thrips taken from *R. communis* at Letaba were found to contain not only *S. aurantii*, as might be expected, but also large numbers of *S. dorsalis*. This was the first record of the latter species from Africa (Gilbert 1986).

S. dorsalis is a pest of citrus in Japan (Mound & Palmer 1981, Hashimoto et al. 1984) and Burma (Anon 1985a) and is therefore clearly a potential threat to this crop (and others) in southern Africa. In other countries, this thrips attacks tea (Kodomari 1978), and chillies (Amin 1979), as well as being a vector of Tomato Spotted Wilt Virus on peanuts (Amin et al. 1981).

In this study the morphology of the larvae and adults of *S. aurantii* and *S. dorsalis* were compared in order to aid future identification.

Materials and methods

First and second instar larvae of the two *Scirtothrips* species were collected, using a small paint brush wetted with ethyl acetate, from *R. communis* growing alongside the experimental orchard. The dead larvae were then transferred to 60% lactic acid and left for 2-3 days for clearing, after which temporary mounts were made in the same solution.

Permanent mounts were made of adult thrips, some of which were first macerated in sodium hydroxide so that setal patterns could be fully examined. Photographs at a magnification of x 400 were taken of the head and metanotum as setal patterns there are important taxonomic characters (Mound & Palmer 1981). Other specimens remained unmacerated to allow colour comparison between the two species (Mound & Pitkin 1972).

Results

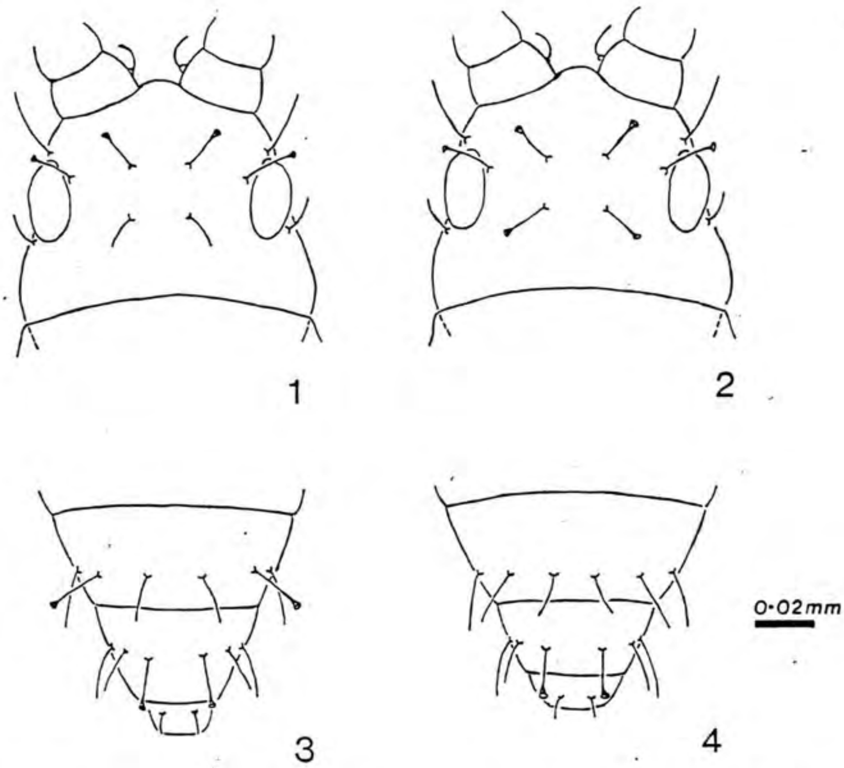
Separation of thrips larvae

The identity of the larvae of each species was confirmed using the emergence method involving Tashiro perspex cages described in chapter 2. There was no obvious difference in the size of the larvae of the two species. As regards colour, the larvae of *S. dorsalis* were a paler yellow than those of *S. aurantii*. Also, differences in setal structure on the dorsal side of the head and segment IX of the abdomen could be seen when examined with the microscope. Two main types of setae were evident: (a) those possessing a thickened ending (clubbed), and (b) simple pointed setae.

When examined under the microscope, a conspicuous arrangement of four setae in a square could be seen on the dorsal side of the head of both species. In *S. dorsalis* the posterior setae were pointed (figure 4.1), whereas in *S. aurantii* they were clubbed (figure 4.2). On the larval abdomen of *S. dorsalis* was inserted a pair of clubbed setae on segment IX. These projected out laterally at an angle of 45° and overlapped the outermost setae when viewed under the microscope (figure 4.3). The corresponding segment of *S. aurantii* bore only pointed setae (figure 4.4).

Separation of thrips adults

Keys for the separation of *Scirtothrips* adults have been prepared by Bailey (1964), and Mound & Palmer (1981), and the following characteristics of the specimens at Letaba agreed with this literature. Specimens of *S. dorsalis* collected at Letaba were pale lemon yellow in colour whereas the thorax of *S. aurantii* was light orange. Females of both species showed dark lines and patches on the abdominal tergites. In *S. dorsalis* the darkened antecostal ridge was confined to the area of the patch. In *S. aurantii* this ridge was more laterally extended. Males of *S. dorsalis* did not always show dark markings on the tergites and in *S. aurantii* these marks were sometimes inconspicuous. However, the presence of hooked drepana on the abdomen and a comb of black setae on the hind femur (Faure 1929) enabled *S. aurantii* males to be distinguished from those of *S. dorsalis* which lack these characters.



Figures 4.1 - 4.4. Heads of second instar larvae, dorsal view; 4.1 *S. dorsalis*. 4.2 *S. aurantii*. Segments IX - XI of larval abdomen; 4.3 *S. dorsalis*. 4.4 *S. aurantii*.

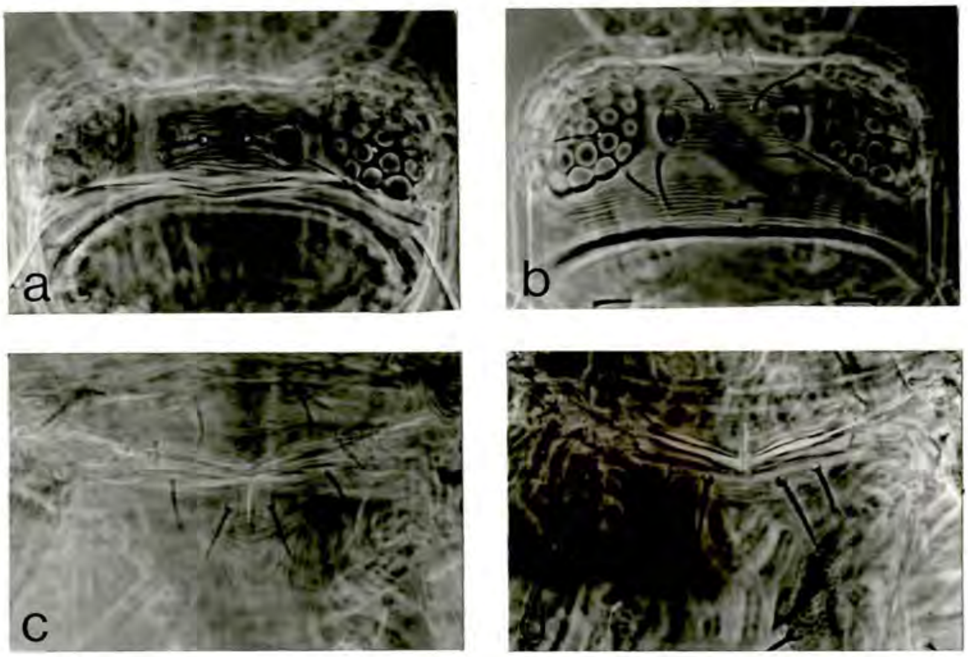


Figure 4.5 (a) and (b) Adult head dorsal view x 400; (a) *S. dorsalis*, (b) *S. aurantii*: (c) and (d) Adult metanotum x 400; (c) *S. dorsalis*, (d) *S. aurantii*.

A pair of small setae was inserted between the two posterior ocelli of *S. dorsalis* (figure 4.5a). The corresponding setae of *S. aurantii* were set further forward at the level of the anterior margin of these ocelli (figure 4.5b).

Two pairs of conspicuous setae were situated on the metanotum. In *S. dorsalis* the median setae were markedly posterior to the lateral pair and set relatively close together (figure 4.5c). The median setae of *S. aurantii* were only slightly posterior to the lateral setae and set wider apart from each other (figure 4.5d). A further confirming character was the presence of straight cilia on the posterior fore-wing of specimens of *S. dorsalis*. On *S. aurantii* these cilia are wavy.

Discussion

Considering the previously recorded range of *S. dorsalis* i.e. Asia, accidental introduction would seem to be the most likely explanation for its appearance in South Africa. Bailey (1964) considered the species to be "... a likely prospect for ready transport in world commerce". It remains to be seen whether *S. dorsalis* achieves pest status in South Africa. At the time of writing, this thrips has not yet been found to damage citrus fruit at Letaba Estates.

5. SEASONAL VARIATION IN ADULT *S.aurantii* NUMBERS IN RELATION TO CITRUS FLUSHING PERIODS, TEMPERATURE AND RAINFALL.

INTRODUCTION

As with any species, the densities of *Scirtothrips aurantii* populations vary at different times of the year and from year to year. A severe outbreak of citrus thrips in one year may be followed by one or more relatively quiet years in which even unsprayed orchards may have little or no damage (Wentzel et al. 1978). In areas such as the northern and north-eastern Transvaal a preventative approach to thrips control is nevertheless followed every year by citrus growers. This traditionally entails the application of a pesticide at the end of the blossom period (which occurs at Letaba in the latter half of September in navel orchards) whether the presence of thrips on the fruitlets has been confirmed or not. Subsequent sprays for thrips are also ideally applied on a preventative basis or at low population levels. This is because severe infestations on the fruit appear to develop in a short time, with consequent rapid economic damage to fruit in the form of permanent scarring of the rind.

Previously published studies of *S. aurantii* numbers have not continued for longer than twelve months in any one particular orchard. Consequently, the magnitude of population variation from year to year in a specific location remains unknown. Bedford (1943) studied *S. aurantii* in the western Transvaal region of Rustenburg, where counts of thrips were conducted during the 1939/40 season. This author noted the presence of citrus thrips on "out-of-season" fruit and suggested that such fruit might maintain thrips during times when soft young foliage and "in-season" fruit was not available.

Stassen and Catling (1969) studied the incidence of *S. aurantii* in Swaziland, sampling thrips directly from young shoots and fruit. More recent work has concentrated on the establishment of economic thresholds for *S. aurantii* by quantified trapping in citrus orchards (Samways et al. 1987, Grout & Richards 1990).

In common with most species of Thysanoptera, *S. aurantii* is bisexual, with females predominating (Hall 1930, Bedford 1943). Both sexes are winged and sticky trapping should therefore yield information on both male and female flight activity. This is in contrast to a species such as *Limothrips denticornis* Haliday in which the males are flightless (Koppa 1969a). Although sticky trapping of *S. aurantii* adults has been carried out with a view to establishing economic thresholds, the sex ratio of the thrips that were caught has not been examined previously.

The aims of the study described in this chapter were:-

a) To record the variation in adult citrus thrips numbers in a single orchard over a period of several years.

b) To record the occurrence of growth flushes of the citrus trees in the experimental orchard and how these related to thrips numbers.

c) To investigate the direct and indirect effects of weather acting on the thrips and their food supply.

d) To examine the comparative flight activity of male and female *S. aurantii* throughout the year, and compare this with the previously recorded female-biased sex ratio.

METHODS

Saturn yellow sticky traps, whose construction and method of exposure in the orchard is described in chapter 2, were used for this study. Trapping commenced in June 1984, traps being set out, exposed for seven days, collected and thrips counted every week. Trapping continued on a weekly basis for six years until May 1990. In addition, weather data (maximum and minimum temperatures as well as rainfall) along with the timing of flush periods of the citrus trees were recorded.

RESULTS

a) Weather data

Rainfall

From June 1983 to May 1990, the mean annual rainfall recorded was 758.96mm, 6.10% lower than the long-term (17-year) average of 808.30mm (table 5.1 & figure 5.1). Between 1983 and 1990, August was the driest month averaging 9.63mm of rain, and December the wettest month with 134.27mm. It is interesting to note that the months of January and February, (which in the long-term are the rainiest months) showed atypically low rainfall over the experimental period. In subsequent sections, the rainfall figures recorded for each individual year are discussed further in connection with the flushing rhythms of the trees and the fluctuations in thrips numbers.

Table 5.1 Summary of rainfall (mm.) recorded at Letaba Estates over the period June 1983 to May 1990.

Month	1983/4	1984/5	1985/6	1986/7	1987/8	1988/9	1989/90	Mean June 1983 - May 1990.	Long-term Mean *
J	0.0	0.0	23.2	3.0	16.5	24.1	36.6	14.77	6.50
J	0.0	77.3	5.2	0.0	0.0	0.0	2.1	12.09	7.80
A	0.0	0.0	0.5	13.5	22.2	16.4	14.8	9.63	12.70
S	0.0	4.2	27.3	4.8	92.4	37.1	0.0	23.69	29.00
O	39.8	105.0	78.9	49.6	44.3	146.7	109.5	81.97	54.90
N	106.1	221.6	60.4	124.4	36.9	14.9	138.8	100.44	91.20
D	105.2	41.9	95.5	159.6	283.8	58.9	195.0	134.27	134.50
J	42.8	142.8	32.9	115.0	87.6	46.0	144.5	87.37	146.00
F	20.0	254.9	82.6	51.6	220.5	99.2	69.5	114.04	148.80
M	195.5	121.1	14.5	93.9	225.9	60.6	110.2	117.38	114.20
A	12.5	3.5	199.5	57.2	4.2	14.7	59.0	50.09	44.70
M	0.0	52.5	11.5	19.5	0.0	7.0	2.0	13.21	18.00
Total	521.9	1024.8	632.0	692.1	1034.3	525.6	882.0	758.96	808.30

* Rainfall data from 1973 to 1990.

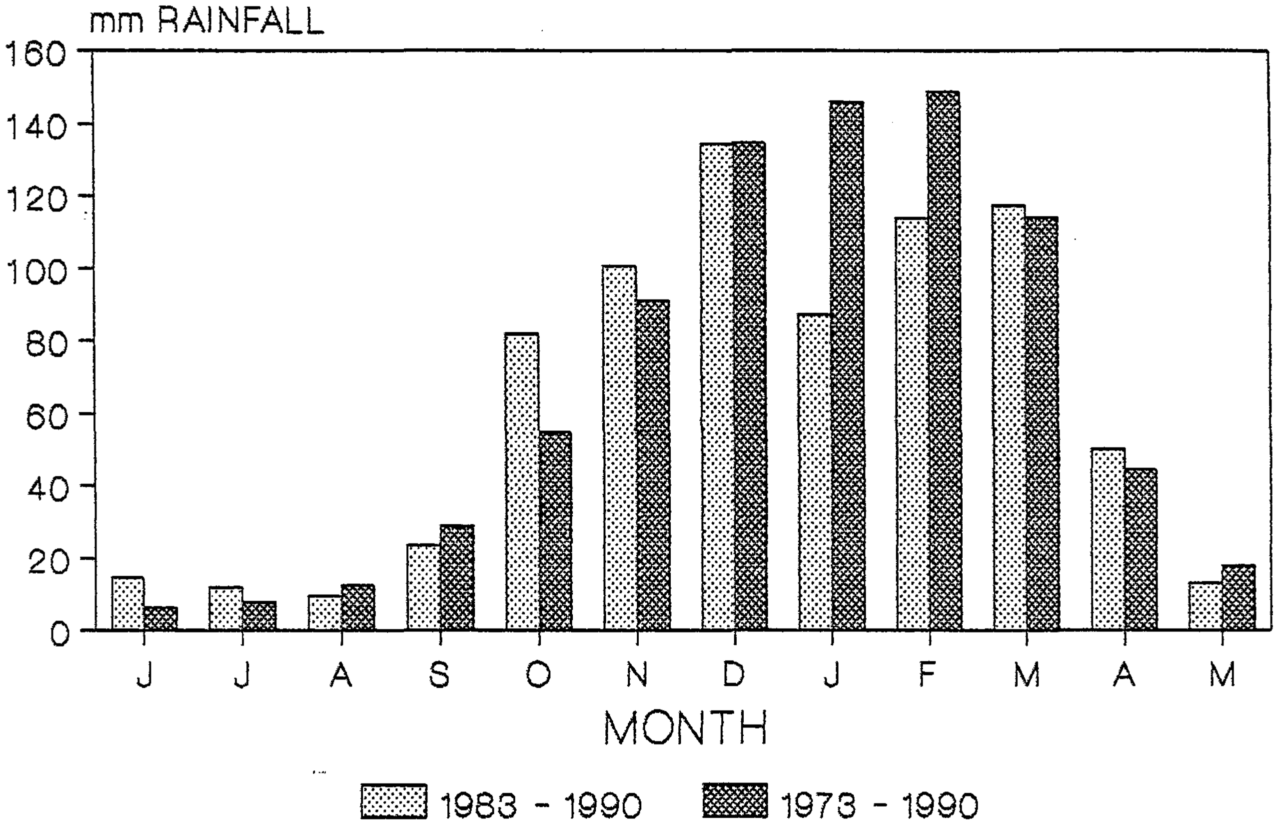


Figure 5.1. Mean monthly rainfall recorded at Letaba Estates from 1983 - 1990 in comparison with that of 1973 - 1990.

Temperature

Table 5.2 summarizes the mean monthly maxima and minima of temperatures for June 1983 - May 1990, as well as the long-term 17-year mean. From June 1983 to May 1990 the mean daily maximum temperature varied from a high of 30.4°C in January to 24.2°C in both June and July. The mean daily minimum temperature varied from 19.9°C in January and February to 8.3°C in June.

b) Fluctuations in adult *S.aurantii* numbers

Over the period of June 1984 to May 1990, a total of 10,257 adult *S. aurantii* were caught on the yellow traps. The totals of thrips caught in each of the twelve monthly periods are shown in figure 5.2. In two years, 1986-87 and 1987-88, very high numbers of thrips were trapped in comparison to the other four years. Factors contributing to the counts within particular years are discussed later on in this chapter. Figure 5.3 records the mean (+ standard error) monthly totals of thrips caught per year over the six year period. Mean numbers of thrips trapped varied from a minimum of 66.83 in August to a maximum of 194.33 in December. Despite these widely-varying figures, Analysis of Variance (ANOVA) followed by Duncan's Multiple Range Test (DMRT) showed no significant differences in thrips numbers between months (all $P > 0.05$). This resulted from the considerable variation in the numbers of citrus thrips caught in the same month in different years.

Figure 5.4 depicts a breakdown of the mean monthly totals of thrips into males and females. The mean catch of males per month varied from a minimum of 26.83 in August to a maximum of 135.00 in September. A comparison of means using ANOVA and DMRT showed

Table 5.2 Mean daily maximum and minimum temperatures (°C) per month from June 1983 - May 1990, and long-term 17-year mean.

	1983/4		1984/5		1985/6	
Month	Max	Min	Max	Min	Max	Min
J	24.9	9.6	24.3	8.0	24.5	8.0
J	24.0	8.3	23.1	9.4	23.9	8.3
A	25.1	8.9	24.8	10.8	25.8	9.4
S	29.9	12.3	27.5	13.1	26.4	13.1
O	26.8	14.8	27.4	16.6	29.3	15.8
N	29.6	18.6	26.2	16.9	29.6	16.8
D	29.7	19.2	30.6	18.6	30.1	18.7
J	31.5	19.1	30.1	19.9	30.9	20.1
F	30.1	18.4	29.2	20.4	30.6	19.4
M	30.1	18.4	28.6	19.1	31.9	17.8
A	26.7	15.4	27.9	14.7	27.6	16.2
M	27.1	10.5	24.9	11.1	27.0	11.5

	1986/7		1987/8		1988/9	
Month	Max	Min	Max	Min	Max	Min
J	24.7	7.3	23.4	7.2	24.2	7.7
J	24.4	6.8	24.3	7.0	25.3	8.2
A	27.8	9.4	24.4	9.8	26.2	10.4
S	27.3	12.5	25.6	14.0	27.9	12.6
O	28.2	15.6	26.0	14.9	26.1	15.9
N	28.9	16.8	29.4	19.3	27.3	15.9
D	29.7	19.4	29.6	21.3	28.5	19.0
J	30.1	20.2	30.9	20.4	30.3	19.3
F	32.9	21.1	29.9	20.9	28.5	20.1
M	30.6	20.3	28.5	20.6	30.5	19.7
A	29.2	17.7	27.8	16.9	26.3	15.8
M	27.8	12.9	26.7	11.7	26.9	12.4

	1989/90		Mean June 1983 - May 1990		Long-term 17-year mean ending 1990	
Month	Max	Min	Max	Min	Max	Min
J	23.7	10.5	24.2	8.3	24.1	8.1
J	24.2	12.6	24.2	8.7	23.9	8.1
A	26.7	11.4	25.8	10.0	25.4	9.8
S	28.7	13.3	27.6	13.0	27.1	12.6
O	28.8	15.3	27.5	15.6	27.7	15.2
N	27.9	17.8	28.4	17.4	28.7	17.3
D	28.5	19.5	29.5	19.4	29.6	18.9
J	29.2	20.3	30.4	19.9	30.2	19.7
F	29.0	18.7	30.0	19.9	29.6	19.7
M	29.0	18.5	29.9	19.2	29.0	18.6
A	26.9	16.6	27.5	16.2	27.5	15.7
M	25.3	11.5	26.5	11.7	26.2	11.4

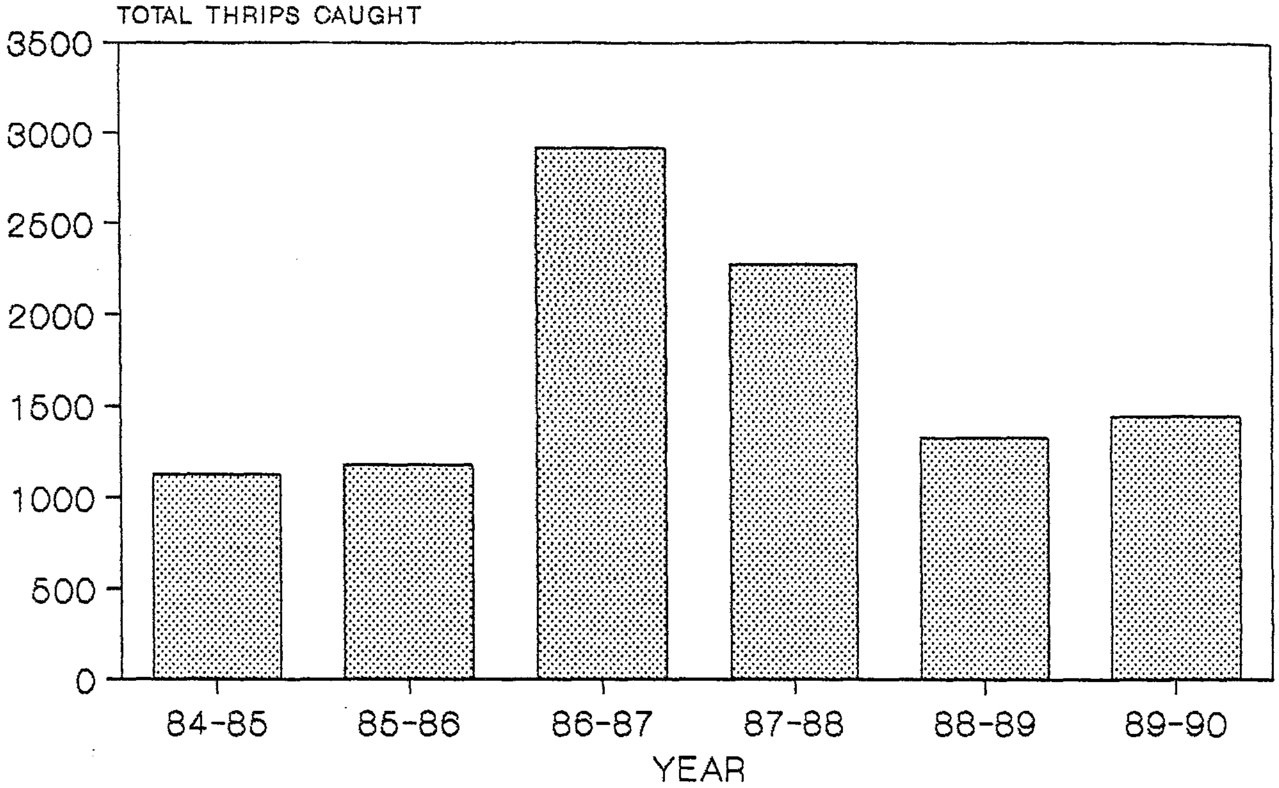


Figure 5.2. Total number of *S. aurantii* recorded on yellow traps per year (June - May) from 1984 - 1990.

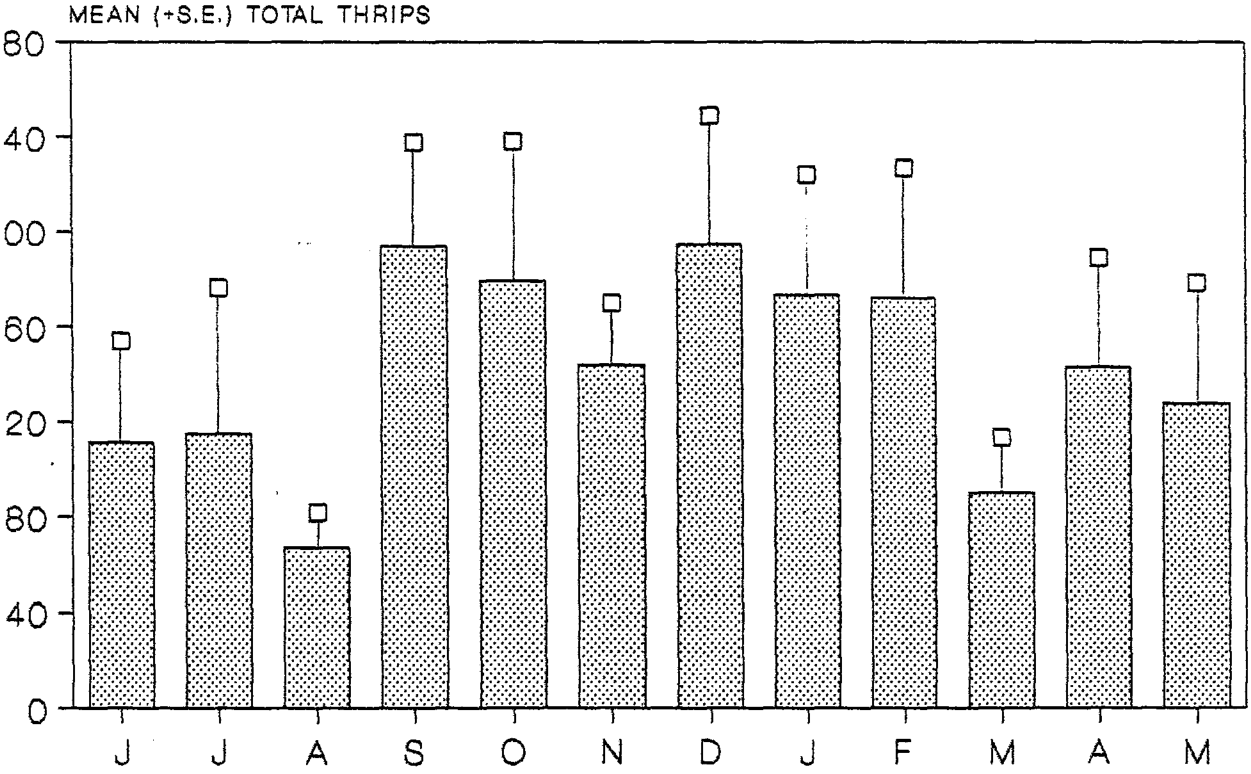


Figure 5.3. Mean (+ standard error of) monthly totals of *S. aurantii* recorded per year on yellow traps, June 1984 - May 1990.

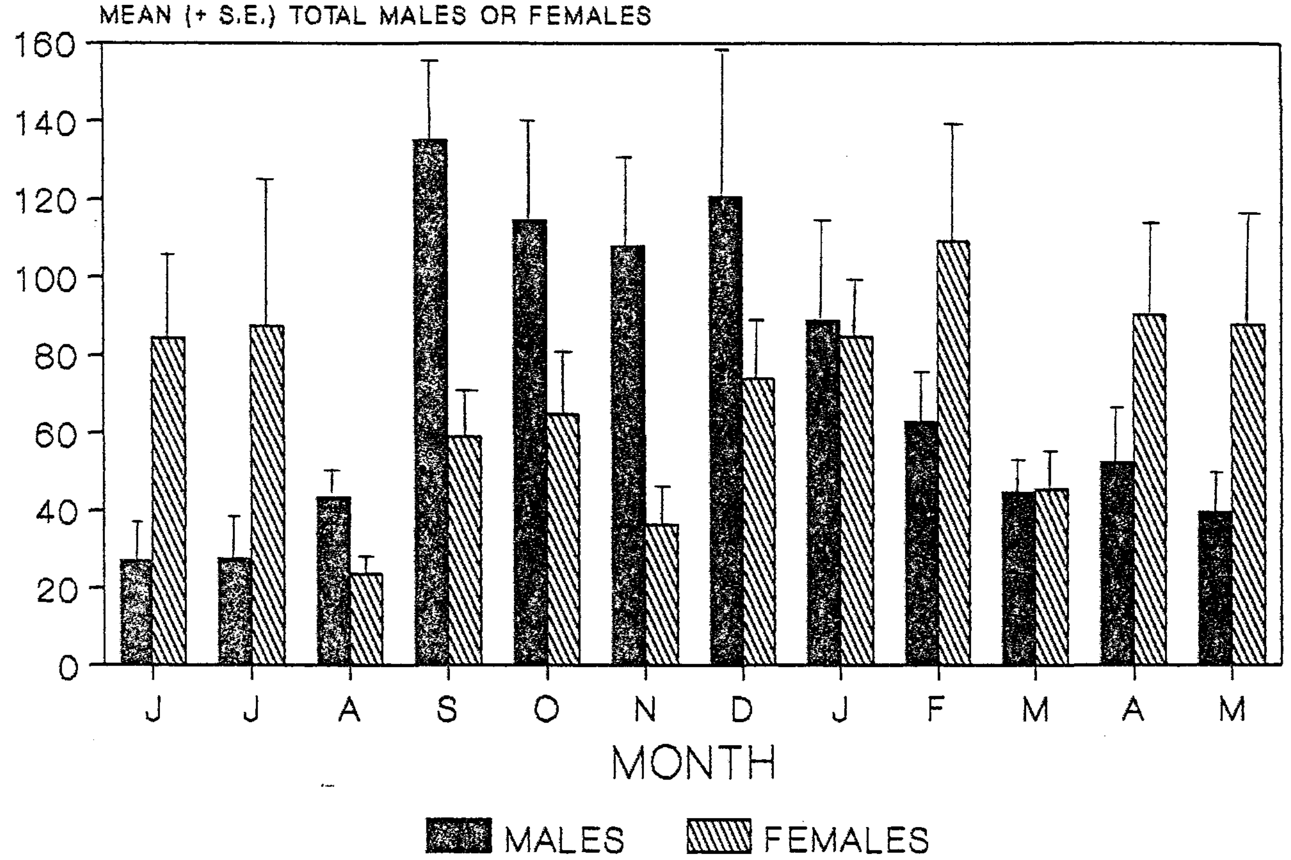


Figure 5.4. Mean (+ standard error of) monthly totals of male and female *S. aurantii* recorded per year on yellow traps, June 1984 - May 1990.

that, over the six-year period, numbers of males trapped in June, July and August were significantly lower than in September ($P < 0.05$). All other months were in the same homogeneous group. With female thrips, the lowest mean of 23.67 per month was recorded in August and the maximum of 109.17 in February. Because of large between-year variations, no significant differences were found between any of the months using ANOVA and DMRT ($P > 0.05$).

c) Seasonal Fluctuations in thrips sex ratio

Over the six-year period 50.48% of the trapped *S.aurantii* were males and 49.52% were females, a ratio of 1 male : 0.98 females (table 5.3). However, looking at the individual months, the percentage of males and females caught varied considerably from the basically 1:1 ratio recorded overall (figure 5.5). When monthly totals of thrips are combined over the six years, the results show a significant excess ($P < 0.05$) of one or other sex in 10 out of the 12 months of the year (table 5.4). Males were trapped in significantly greater numbers than females in five months; August, September, October, November and December. Similarly, females were trapped in significantly greater numbers than males in five months; June, July, February, April and May. There was no significant excess of either males or females in the remaining two months of January and March.

Figure 5.6 indicates for each month the number of years in which a significant excess of one or other sex was recorded. In the first two months of winter, June and July, females were caught in significantly greater numbers than males in five out of the six years. In August the proportion of the sexes trapped is completely different, with four of the years showing a

Table 5.3 Mean monthly percentages of male and female *S.aurantii* recorded on yellow traps, June 1984 - May 1990. For analysis, DMRT was used on arcsine square root transformed data. Means followed by the same letter were in the same group (P > 0.05).

	Month	Mean % Males	Mean % Females	Homogeneous Groups
WINTER	June	24.14	75.86	a
	July	23.84	76.16	a
	August	64.59	35.41	ef
SPRING	September	69.65	30.35	def
	October	63.87	36.13	cdef
	November	74.77	25.23	f
SUMMER	December	62.01	37.99	bcdef
	January	51.25	48.75	bcd
	February	36.53	63.47	abc
AUTUMN	March	49.63	50.37	bcde
	April	36.64	63.36	ab
	May	30.98	69.02	ab
	Whole year	50.48	49.52	

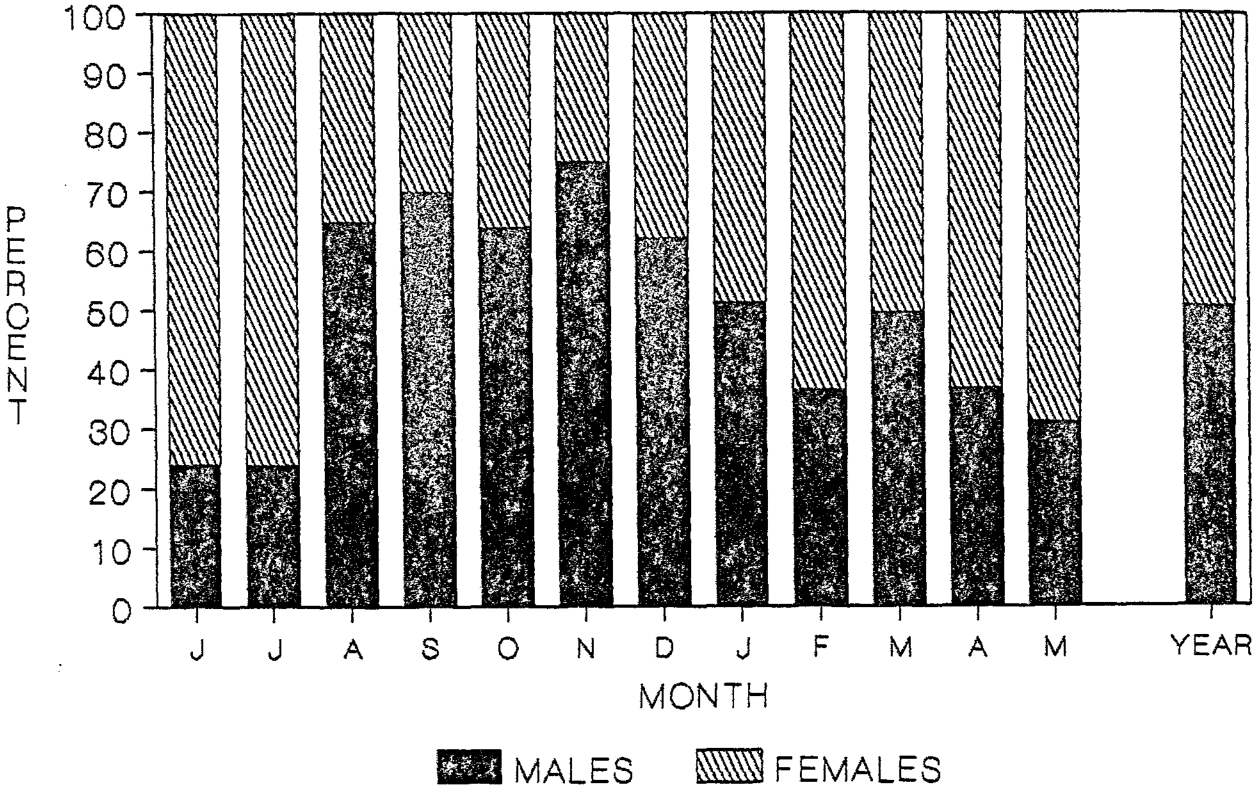


Figure 5.5. Mean monthly percentages of male and female *S. aurantii* recorded on yellow traps, June 1984 - May 1990.

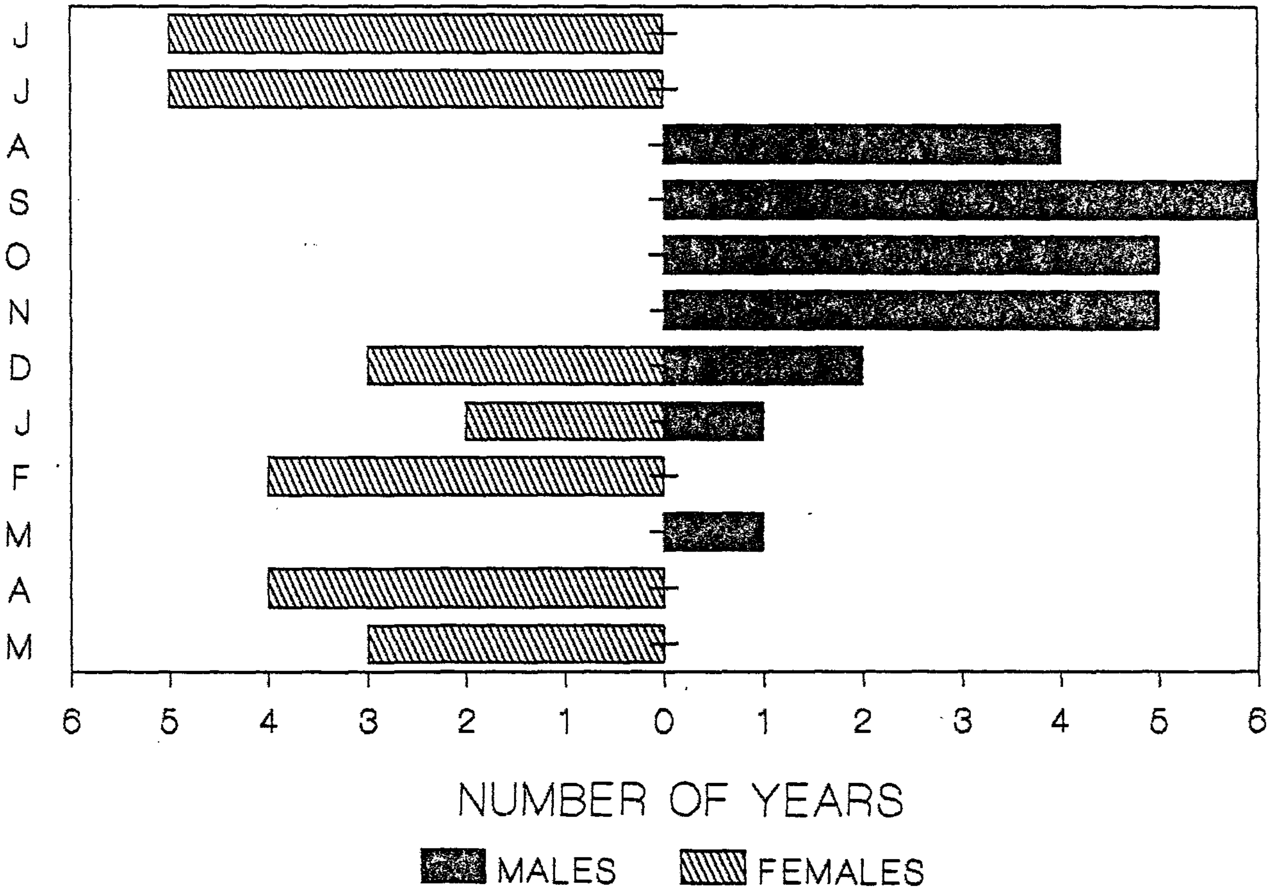


Figure 5.6. Summary of the analysis of monthly proportions of male and female *S. aurantii* recorded on yellow traps, June 1984 - May 1990, to show the number of years where there was a significant excess of one or other sex.

Table 5.4 Analysis of monthly totals per year (± Standard Error between years) of adult *S. aurantii* recorded on sticky yellow traps over the period June 1984 - May 1990, and a comparison of the total numbers of males and females. X^2 values refer to a comparison with 1:1 sex ratio.

Month	Mean total thrips trapped (± S.E.)	Males	Females	X^2	P	Excess	
June	111.10 ± 42.46	161	506	178.45	<0.001	F	***
July	114.60 ± 61.32	164	524	188.37	<0.001	F	***
August	66.83 ± 14.70	259	142	34.14	<0.001	M	***
September	193.60 ± 43.84	810	353	179.85	<0.001	M	***
October	179.00 ± 58.93	686	388	82.69	<0.001	M	***
November	144.00 ± 25.69	646	218	212.02	<0.001	M	***
December	194.30 ± 54.39	723	443	67.23	<0.001	M	***
January	173.30 ± 50.45	533	507	0.65	0.42	-	N.S.
February	172.00 ± 54.37	377	655	74.89	<0.001	F	***
March	90.00 ± 23.23	268	272	0.03	0.86	-	N.S.
April	142.80 ± 45.85	314	543	61.19	<0.001	F	***
May	127.50 ± 50.63	237	528	110.69	<0.001	F	***
Total	1709.50 ±295.15	5178	5079	0.36	0.55	-	N.S.

significant excess of males. The most consistent results were obtained in the month of September in that significantly more males than females were trapped in all six years of the study. This month along with August, October, November and March were similar in that in none of the years was an excess of females recorded. From December onwards the tendency is for proportionately more females to be trapped, and in the months of February, April, May, June and July an excess of males was never recorded. In December and January the dominant sex fluctuated between years.

Mean monthly percentages of males and females caught are shown in table 5.3. In order to compare results within and between the six years, the percentage data were first transformed using the arcsine square root transformation (Snedecor & Cochran 1967) and then analyzed using DMRT. Statistical analysis identified six groups (a, b, c, d, e, and f) whose between-group means differed significantly ($P < 0.05$, table 5.4). During the winter months of June and July only 24.14% and 23.84% males were caught respectively. However during August (still winter) the mean male percentage increased to 64.59% and, for the next five months, remained above 50%, significantly greater than that of June and July. There was a clear trend for the percentage of males to decrease from November onwards, when the highest mean male catch of 74.77% was recorded (figure 5.5).

d) Variation in adult thrips numbers in relation to the flushing pattern of the citrus trees, rainfall and temperature in individual years.

June 1984 - May 1985

Although trapping did not commence until June 1984, weather data were collected, and flush periods noted during the whole of that year. January and February of 1984 experienced very low rainfall (table 5.1) with only 42.8 and 20mm recorded respectively in comparison to the long-term average of 146.0 and 148.8mm. This placed the trees under severe moisture stress and caused a certain degree of wilting. In March, unusually high rainfall was recorded, (195.5mm in comparison to the long-term average of 114.2mm), which caused the trees to flush and also to blossom during April and May. After flowering ended in late May, the presence of a considerable number of out-of-season fruit was noted.

The spring flush began to appear in the latter half of July, and finished in mid-September (figures 5.7 & 5.8). The second flush of the growing season began to show in October and lasted until mid-November. It's relatively early appearance was a reaction to the severe damage caused to the trees by a hailstorm which a large area of the estate experienced on 13th September 1984. Many trees were stripped of their flowers and a proportion of their leaf canopy.

Continuing into 1985, the first three months showed a very different distribution of rainfall compared to the previous year. High rainfall in January and February caused the appearance of a third flush early in the year, and these leaves had already hardened off by the end of March with no out-of-season fruit being set (figure 5.7). This would be expected to create a shortage of food for thrips during late autumn and winter 1985.

During this 12 month period a total of 1124 thrips were caught on the sticky traps. In contrast to most subsequent years, the highest numbers occurred during winter, in late June and early July 1984 (figure 5.8). As noted above, a late autumn flush and out-of-season fruit set occurred after heavy rain in March 1984, and this apparently formed a highly suitable food source for *S. aurantii* during that winter. Numbers of citrus thrips were generally lower after petal-fall in September than during the previous winter. It is possible that the severe hailstorm may have been responsible for this by causing high thrips mortality, as the advent of the hailstorm coincided with a reduction in thrips numbers just at the time when adult numbers began to increase in subsequent years. During the rest of this sample period thrips numbers were generally low, and the poorly-defined peak after the third flush reflected this.

During this sampling period, 477 males and 647 females were trapped, with overall a significant excess of the latter ($P < 0.001$, table 5.5a). Similarly, at the start of the trapping period, during June and July, females were more abundant than males (figure 5.9). However in August, the number of females trapped declined sharply to 56 in comparison to 122 in July, whereas male numbers remained approximately the same in July and August (table 5.5a). The overall effect was that males represented 51.72% of the total trapped in August in contrast to the roughly 30% in the two previous months. The proportion of males trapped was also significantly greater than that of females in the following three months. Weekly results of percentages caught were very erratic for much of the rest of this sampling period due to the small numbers of individuals that were trapped

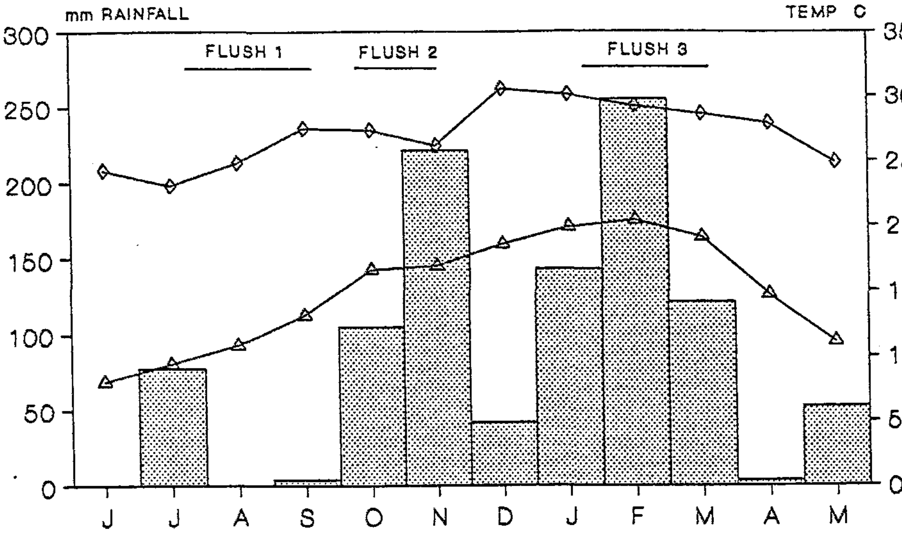


Figure 5.7. Monthly rainfall, mean daily maximum (◇) and minimum temperature (△), and the occurrence of flush periods on the citrus trees, June 1984 - May 1985.

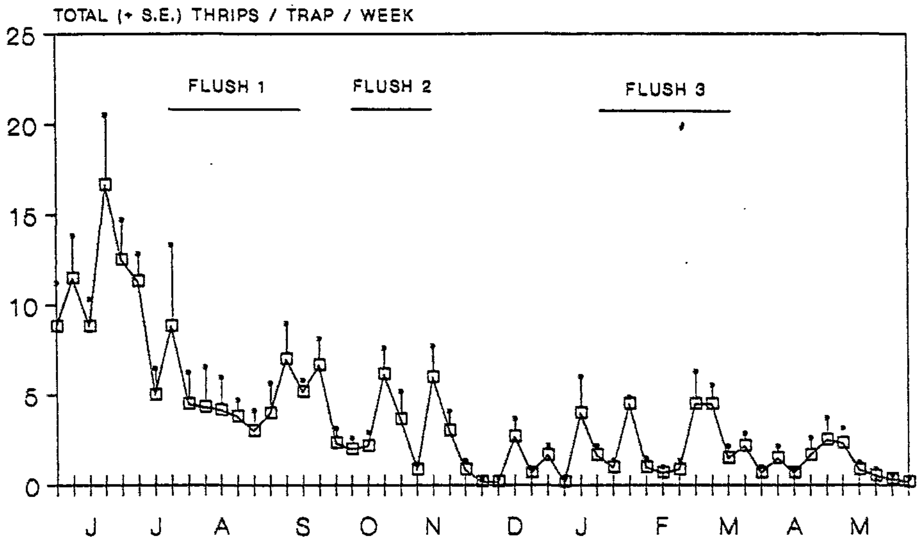


Figure 5.8. Mean (+ standard error of) weekly numbers of adult *S. aurantii* recorded on sticky yellow traps, and the timing of flush periods of the citrus trees, June 1984 to May 1985.

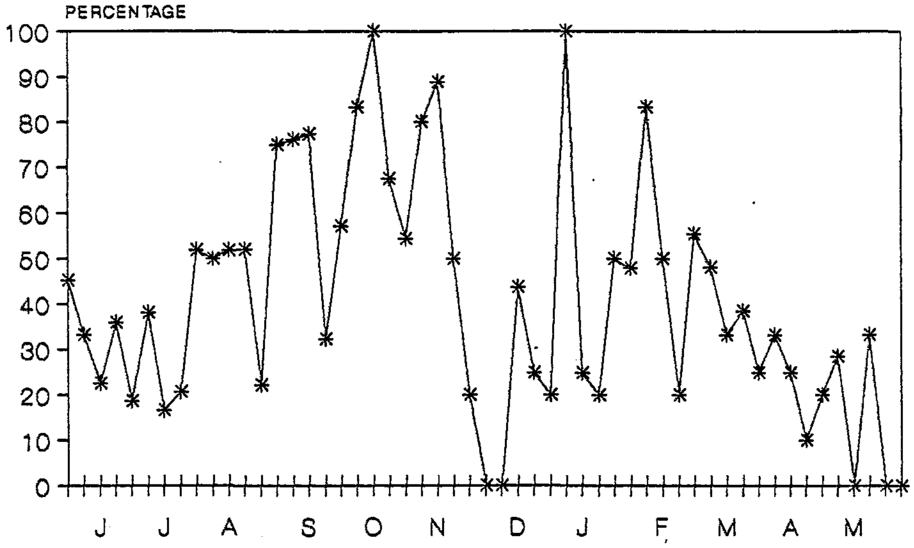


Figure 5.9. Mean weekly percentage of male *S. aurantii* in total recorded on sticky yellow traps, June 1984 to May 1985.

Table 5.5a & b. Numbers of male and female adult *S. aurantii* caught per month on sticky yellow traps 1984-85 and 1985-86. X^2 values refer to a comparison with a 1:1 sex ratio.

a) <u>1984-85</u>

Month	Males	Females	% Males	X^2	P	Excess	
June	85	212	28.62	54.31	<0.001	F	***
July	56	122	31.46	24.47	<0.001	F	***
Aug	60	56	51.72	0.14	0.71	-	N.S.
Sept	77	50	60.63	5.74	0.02	M	*
Oct	60	24	71.43	15.43	<0.001	M	***
Nov	46	19	70.77	11.22	<0.001	M	***
Dec	10	21	32.26	3.90	0.05	F	*
Jan	25	43	36.76	4.76	0.03	F	*
Feb	23	19	54.76	0.38	0.54	-	N.S.
Mar	22	31	41.51	1.53	0.22	-	N.S.
Apr	8	30	21.05	12.74	<0.001	F	***
May	5	20	20.00	9.00	<0.001	F	***
Total	477	647	42.44	27.24	<0.001	F	***

b) <u>1985-86</u>

Month	Males	Females	% Males	X^2	P	Excess	
June	1	4	20.00	1.80	0.18	-	N.S.
July	2	9	18.18	4.45	0.03	F	*
August	21	4	84.00	11.56	<0.001	M	***
September	18	8	69.23	3.85	0.05	M	*
October	10	19	34.48	2.79	0.09	-	N.S.
November	46	33	58.22	2.14	0.14	-	N.S.
December	60	102	37.04	10.89	<0.001	F	***
January	101	90	52.88	0.63	0.43	-	N.S.
February	60	38	61.22	4.94	0.03	F	*
March	64	69	48.12	0.19	0.66	-	N.S.
April	97	134	41.99	5.93	0.01	F	**
May	103	82	55.68	2.38	0.12	-	N.S.
Total	583	592	49.62	0.07	0.79	-	N.S.

Table 5.5c & d. Numbers of male and female adult *S. aurantii* caught per month on sticky yellow traps, 1986 - 87 and 1987 - 88. X^2 values refer to a comparison with a 1:1 sex ratio.

c) <u>1986-87</u>

Month	Males	Females	% Males	X^2	P	Excess	
June	36	94	27.69	25.88	<0.001	F	***
July	78	317	19.75	144.61	<0.001	F	***
Aug	31	39	44.29	0.91	0.33	-	N.S.
Sept	202	53	79.22	87.06	<0.001	M	***
Oct	245	137	64.14	30.53	<0.001	M	***
Nov	177	21	89.39	122.91	<0.001	M	***
Dec	374	61	85.98	225.22	<0.001	M	***
Jan	242	155	60.96	19.07	<0.001	M	***
Feb	54	190	22.13	78.80	<0.001	F	***
March	33	42	44.00	1.08	0.29	-	N.S.
April	109	99	52.40	0.48	0.49	-	N.S.
May	28	97	22.40	38.09	<0.001	F	***
Total	1609	1305	55.22	31.71	<0.001	M	***

d) <u>1987-88</u>

Month	Males	Females	% Males	X^2	P	Excess	
June	10	55	15.38	31.15	<0.001	F	***
July	8	36	18.18	17.82	<0.001	F	***
August	29	7	80.56	13.44	<0.001	M	***
September	114	63	64.41	14.69	<0.001	M	***
October	205	130	87.23	16.79	<0.001	M	***
November	107	71	60.11	7.28	<0.001	M	***
December	69	97	41.57	4.72	0.03	F	*
January	79	124	38.92	9.98	<0.001	F	***
February	125	266	31.97	50.85	<0.001	F	***
March	32	12	72.72	9.09	<0.001	M	***
April	67	221	23.26	82.35	<0.001	F	***
May	68	278	19.65	127.46	<0.001	F	***
Total	913	1360	40.17	87.91	<0.001	F	***

Table 5.5e & f. Numbers of male and female adult *S. aurantii* caught per month on sticky yellow traps, 1988 - 89 and 1989 - 90. X^2 values refer to a comparison with a 1:1 sex ratio.

e) <u>1988-89</u>

Month	Males	Females	% Males	X^2	P	Excess	
June	19	113	14.39	66.94	<0.001	F	***
July	5	17	22.73	6.55	0.01	F	**
Aug	41	12	77.36	15.87	<0.001	M	***
Sept	222	105	67.89	41.86	<0.001	M	***
Oct	84	56	60.00	5.60	0.02	M	***
Nov	98	31	75.97	34.80	<0.001	M	***
Dec	114	105	52.05	0.37	0.54	-	N.S.
Jan	42	36	53.85	0.46	0.50	-	N.S.
Feb	17	43	28.33	11.27	<0.001	F	***
March	26	24	52.00	0.08	0.78	-	N.S.
April	22	35	38.60	2.96	0.09	-	N.S.
May	25	36	40.98	1.98	0.16	-	N.S.
Total	715	613	53.84	7.83	<0.001	M	***

f) <u>1989-90</u>

Month	Males	Females	% Males	X^2	P	Excess	
June	10	28	26.32	8.53	<0.001	F	***
July	15	23	39.47	1.68	0.19	-	N.S.
August	77	24	76.24	27.81	<0.001	M	***
September	177	74	70.52	42.27	<0.001	M	***
October	82	22	78.85	34.62	<0.001	M	***
November	172	43	80.00	77.40	<0.001	M	***
December	96	57	62.75	9.94	<0.001	M	***
January	44	59	42.72	2.18	0.14	-	N.S.
February	98	99	49.75	0.00	0.94	-	N.S.
March	91	94	49.19	0.05	0.83	-	N.S.
April	11	24	31.43	4.83	0.03	F	*
May	8	15	34.78	2.13	0.14	-	N.S.
Total	881	562	61.05	70.52	<0.001	M	***

per week (figures 5.8 and 5.9). Analysis of monthly totals reveals that, after November, there was a shift from male- to female-dominated catches in December and January (table 5.5a). During February and March the proportions of the two sexes were not significantly different. During April and May, females again dominated the monthly results.

June 1985 - May 1986

As noted in the previous section, no out-of-season fruit were present during the winter of 1985. The first flush of the growing season began to appear during the latter half of July and lasted until mid-September (figure 5.10). The second flush occurred from late October until the end of November. Following 95.5mm of rainfall in December, a third sparse flush was initiated during January 1986. Rainfall during the first three months of 1986 was exceptionally low, with a total of only 130mm being recorded compared to a long-term average of 409mm (figure 5.10 and table 5.1).

It was not until April that substantial rain was recorded, the total for the month being 199.5mm, of which nearly all occurred in a single week. This amount of April rain was far in excess of the long-term average of 44.7mm at Letaba, and stimulated a fourth growth flush and heavy out-of-season fruit set (figure 5.10). This growth flush began later in autumn than any other recorded during the study period.

The total number of *S. aurantii* trapped during this sampling period was 1175, similar to the total recorded in 1984-5. However in contrast to 1984, numbers of thrips during winter 1985 were minimal, this continued into spring and, during September, only

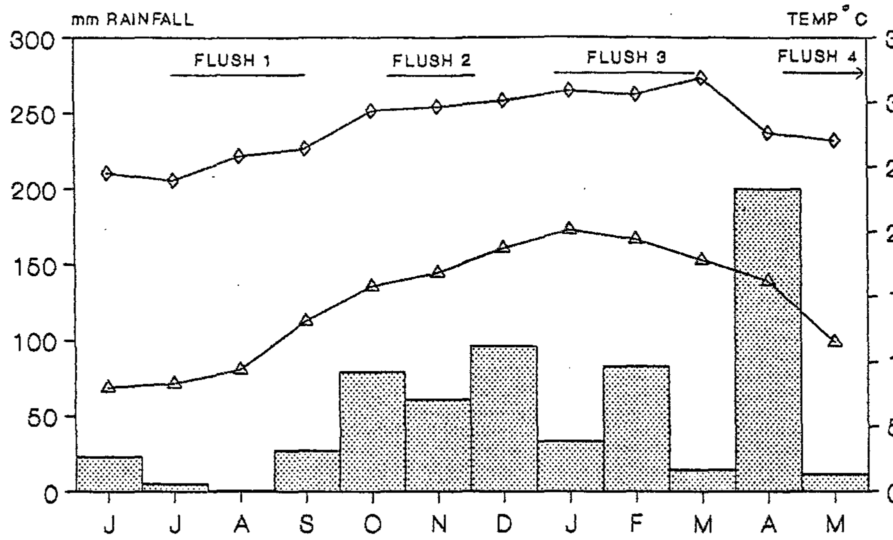


Figure 5.10. Monthly rainfall, mean daily maximum (◇) and minimum temperature (△), and the occurrence of flush periods on the citrus trees, June 1985 - May 1986.

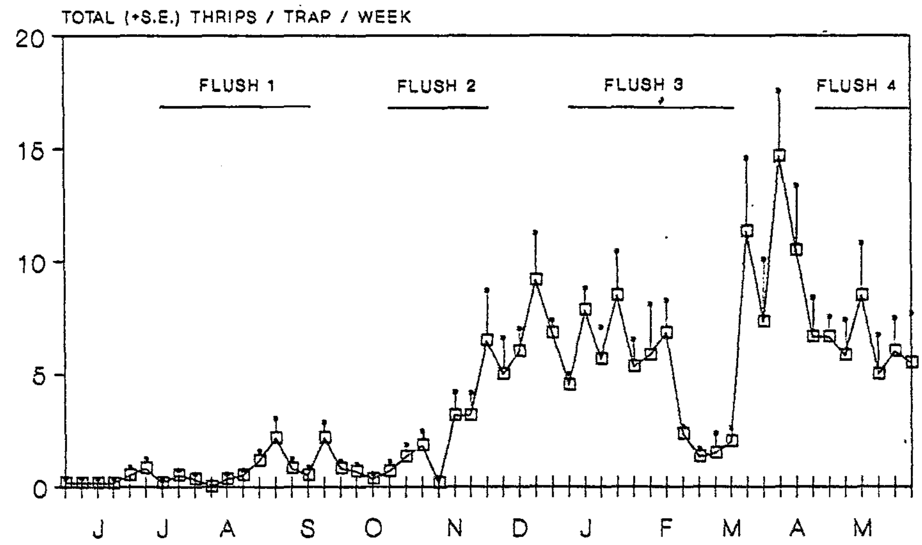


Figure 5.11. Mean (+ standard error of) weekly numbers of adult *S. aurantii* recorded on sticky yellow traps, and the timing of flush periods of the citrus trees, June 1985 to May 1986.

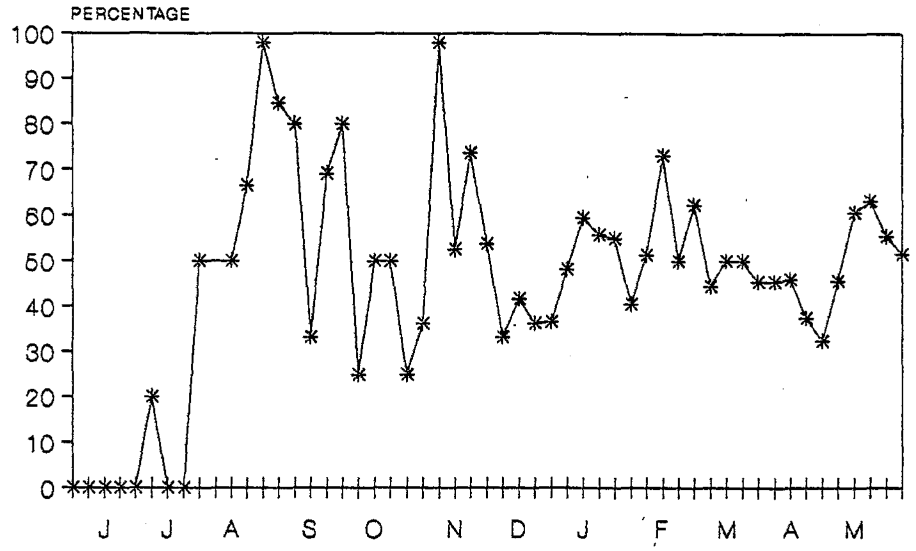


Figure 5.12. Mean weekly percentage of male *S. aurantii* in total recorded on sticky yellow traps, June 1985 to May 1986.

two very small peaks were recorded (figure 5.11). Numbers did not start to rise significantly until the latter half of November, towards the end of the second flush. The particularly late fourth flush of the growing season provided an additional food source for the large numbers of thrips that were present during the latter half of autumn. Maximum numbers of thrips were recorded on the traps in the period between the third and fourth flushes.

Of the 1175 thrips caught in these twelve months, 583 were males and 592 were females (table 5.5b). There was no significant excess of one or other sex overall, in contrast to 1984 - 85 when females predominated. During June and July 1985 the majority of thrips caught were females although, due to low numbers, significance could only be demonstrated in the latter month. Overall, there was a predominance of males during August to September, although the low numbers caused a considerable variation in the weekly percentages recorded (figure 5.12). An apparent increase in male percentages was associated with each of the four flush periods.

June 1986 - May 1987

This time period was unique in having a flush present during the first half of June (figure 5.13), after which out-of-season fruit could be seen on the trees. This followed unusually high rainfall in April 1986 (see previous section). The rainfall of the first three months of 1987 was again well below average (table 5.1) and during January and February very little new growth was present on the trees. A fourth flush started to show in the middle of March. The generally low rainfall was probably the reason why no

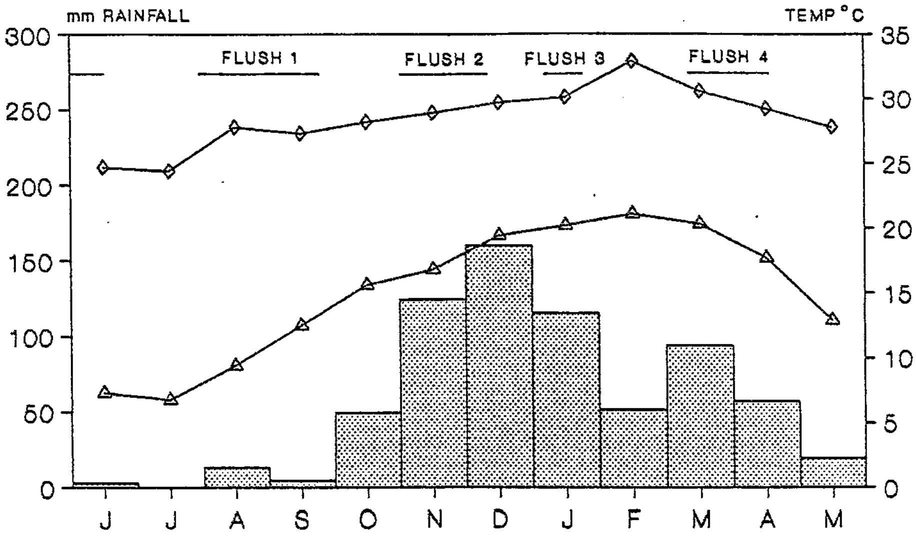


Figure 5.13. Monthly rainfall, mean daily maximum (◊) and minimum temperature (△), and the occurrence of flush periods on the citrus trees, June 1986 - May 1987.

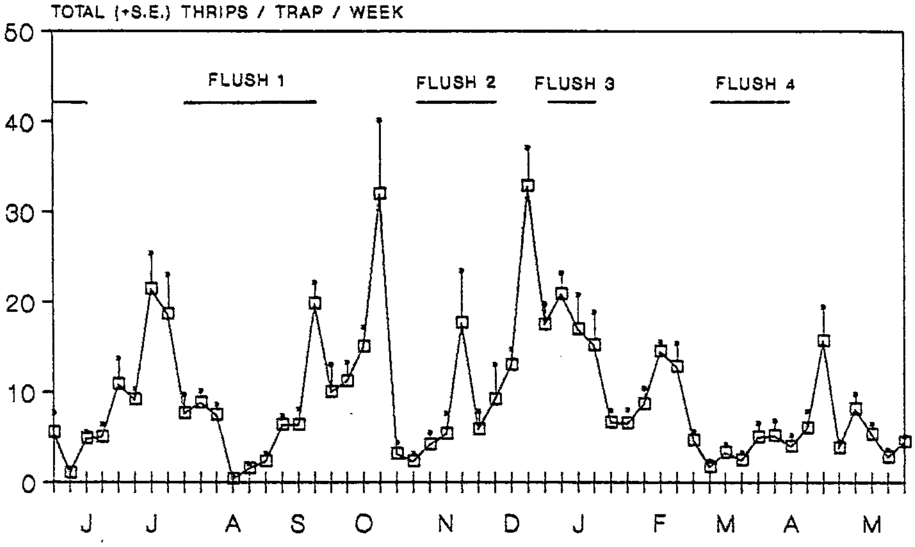


Figure 5.14. Mean (+ standard error of) weekly numbers of adult *S. aurantii* recorded on sticky yellow traps, and the timing of flush periods of the citrus trees, June 1986 to May 1987.

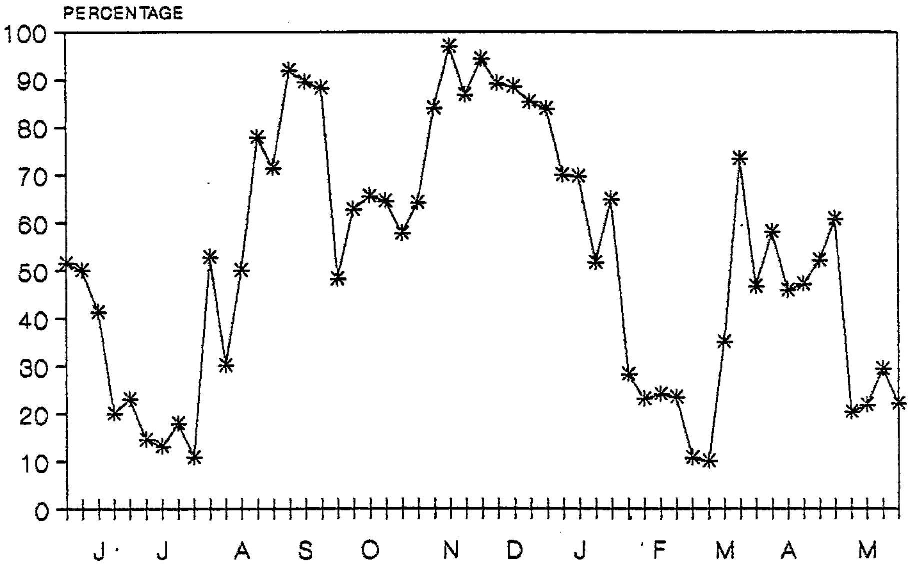


Figure 5.15. Mean weekly percentage of male *S. aurantii* in total recorded on sticky yellow traps, June 1986 to May 1987.

out-of-season fruit was set as high rainfall during March or April might have resulted in a repeat of the pattern of 1986. As it was, the autumn flush hardened off by mid-April.

The 2914 thrips trapped during these twelve months was more than twice the number recorded in the whole of the previous 24 months (figure 5.2). It was also higher than any of the three subsequent years studied. During the winter of 1986 there was a continuous supply of food for *S. aurantii* because of the very late flush and out-of-season fruit present. The adult thrips population peaked in the middle of July at a mean level of over 20 thrips per trap (figure 5.14), despite the colder weather of winter. This peak number was in excess of any figures recorded during the whole of 1984 and 1985. The peaks subsequently recorded during spring and summer 1986 were also particularly high. The onset of each flush period was usually accompanied by an increase in the percentage of male *S. aurantii* that were caught (figure 5.15). The high numbers of thrips over this period made this pattern particularly clear. Following the peak of adult thrips at the end of April 1987, the population declined throughout the rest of autumn.

The year's thrips total comprised 1609 males and 1305 females, with an overall excess of males (table 5.5c). 9 of the 12 months showed a significant dominance of one or other sex. June and July were female-dominated, whereas September to January were male-dominated. August represented a transition stage in which the proportions of the sexes were not significantly different from a 1:1 ratio. From February to May 1987, two of the months showed a significantly higher proportion of females.

June 1987 - May 1988

In contrast to 1986, no late flush or out-of-season fruit was present during June and July 1987. The spring flush appeared at the beginning of August, but this year was unusual in that the second flush did not appear until late December, perhaps due in part to lower than average rainfall during October and November (figure 5.16). Unfortunately, no direct observations were made regarding the timing of the third flush period of the growing season as I was abroad from the beginning of March until the end of April. However on my return it could be seen that a flush had recently hardened off and that no out-of-season fruit had been set. Looking at figure 5.18 and the increase in male percentage which started in late February, one can estimate that the third flush began at about this time. As a large peak of thrips occurred during the latter half of April and in early May, it is likely that the leaves of this flush hardened off sometime around mid-April.

In this sample period, a total of 2273 thrips were trapped, the second highest total of the six-year study (figure 5.2). Thrips numbers were much lower throughout the winter of 1987 than in 1986, correlated with a lack of late flush or out-of-season fruit. Thrips numbers began increasing from the middle of August (figure 5.17), with the spring peak occurring on the 12th October. Two other main peaks were recorded during the sampling period, each following the flush periods.

Of the total of 2273 thrips caught, 913 were males and 1360 were females (table 5.5d). As in previous years the onset of the first flush was correlated with a marked increase in the percentage of males trapped (figure 5.18) to as high as 100% in

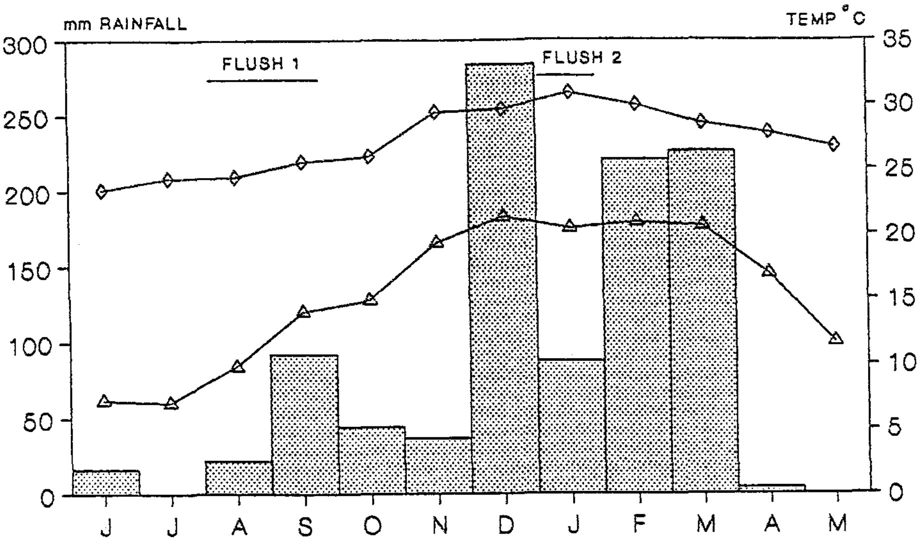


Figure 5.16. Monthly rainfall, mean daily maximum (◇) and minimum temperature (△), and the occurrence of flush periods on the citrus trees, June 1987 - May 1988.

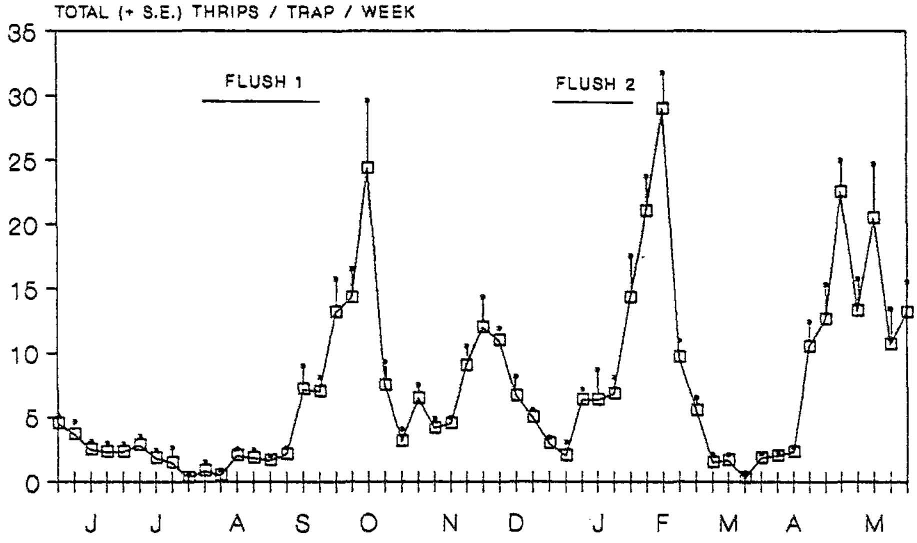


Figure 5.17. Mean (+ standard error of) weekly numbers of adult *S. aurantii* recorded on sticky yellow traps, and the timing of flush periods of the citrus trees, June 1987 to May 1988.

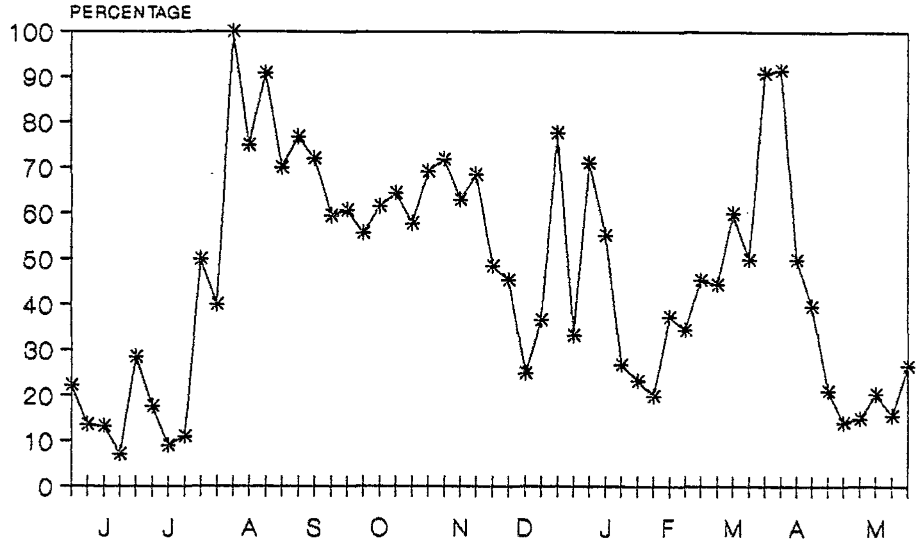


Figure 5.18. Mean weekly percentage of male *S. aurantii* in total recorded on sticky yellow traps, June 1987 to May 1988.

mid-August. From this month until November, the results showed a significant excess of males over females (table 5.5d). In mid-December the male percentage dropped below 30% in one particular week, the average for the month being 41.57%. For the rest of the sample period except for March, all other months showed a significant excess of females.

Regarding weekly counts, the male percentage again increased with the onset of the second flush and declined during late January as the leaves hardened off. As mentioned above, my absence from the country prevented the direct observation of the beginning of the third flush, but looking at figure 5.18 it seems likely that it began in the latter half of February as the male percentage rose sharply at this time to a peak in early April. There then followed a peak in total numbers of thrips caught (figure 5.18) which, as we have seen, was usually associated with the hardening off of a particular flush.

June 1988 - May 1989

No out-of-season fruit were set during the winter of 1988, and the first flush of the growing season appeared at the beginning of August, followed by a second in November (figure 5.19). During the first quarter of 1989, rainfall was yet again well below average, and it was observed that during this period, two sparse flushes occurred on the trees. The last of these had hardened off by the end of March and no out-of-season fruit was set.

A total of 1328 thrips were caught during this 12 month period, far less than in 1986-87 or 1987-88 (figure 5.2). After the spring flush, the largest peak of thrips numbers was recorded and a second peak followed the second flush. These peaks were both

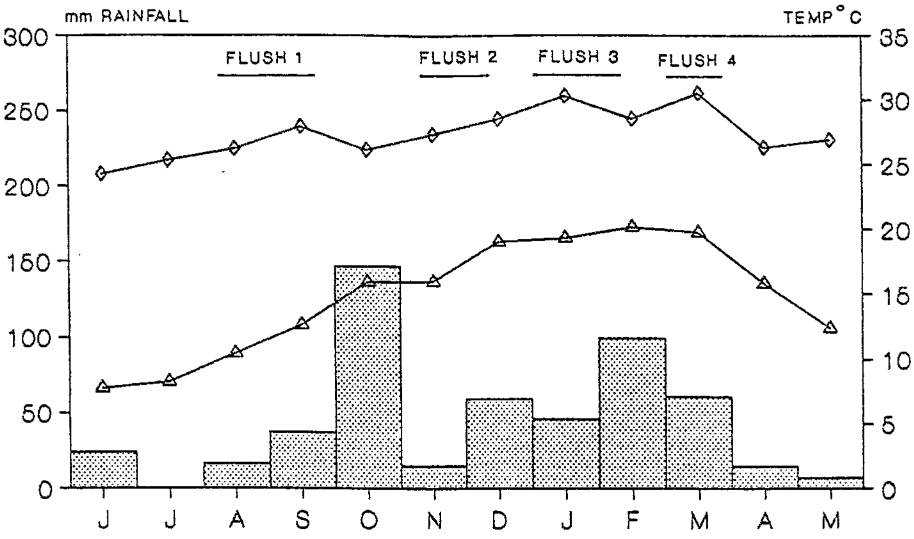


Figure 5.19. Monthly rainfall, mean daily maximum (◇) and minimum temperature (△), and the occurrence of flush periods on the citrus trees, June 1988 - May 1989.

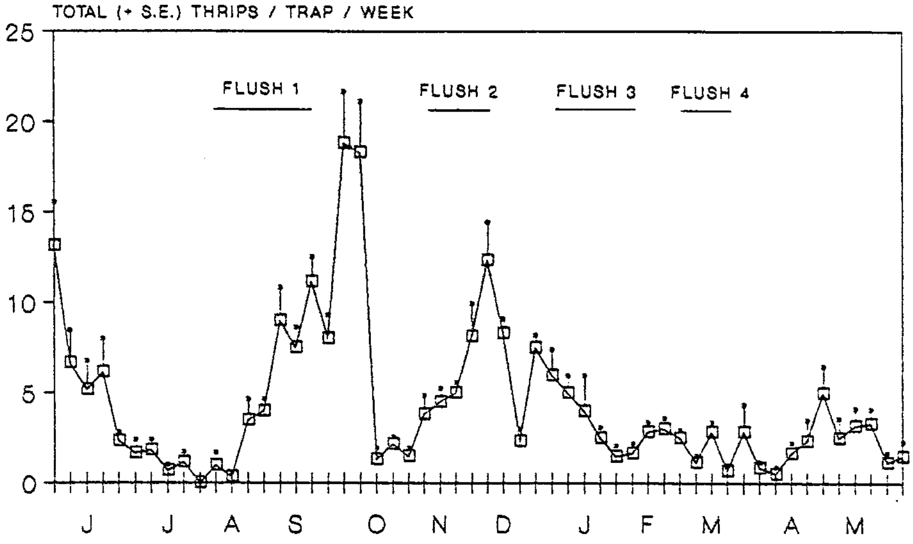


Figure 5.20. Mean (+ standard error of) weekly numbers of adult *S. aurantii* recorded on sticky yellow traps, and the timing of flush periods of the citrus trees, June 1988 to May 1989.

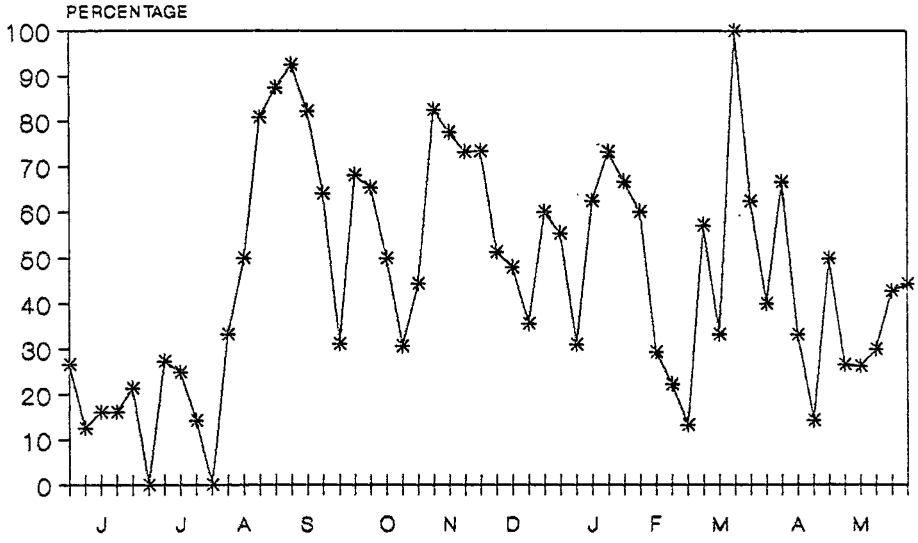


Figure 5.21. Mean weekly percentage of male *S. aurantii* in total recorded on sticky yellow traps, June 1988 to May 1989.

recorded during the main period of fruit susceptibility (figure 5.20), the first soon after petal-fall and the second in early December. The population peak observed in late April was low in comparison to that associated with the last flush of the previous three years.

Of the 1328 thrips caught, 715 were males and 613 were females, a significant excess of males (table 5.5e). The percentage males trapped increased consistently from the beginning of August until mid-September reaching a peak of over 90% (figure 5.21). From August to November, the traps recorded a significant excess of males. A second smaller peak in the male percentage was recorded during the first half of October and a larger one associated with the second flush. The sex ratios were rather erratic during the latter half of the period due to generally low numbers of thrips caught.

June 1989 - May 1990

No out-of-season fruit were set during the winter of 1989. The first flush of the 1989 - 1990 growing year began to show in early August (figure 5.22). The second flush occurred from late October to late November and the third from early February to late March.

A total of 1443 thrips were trapped during this sampling period. The first major peak of thrips occurred during mid-September, as the first flush was hardening off (figure 5.23). Total numbers of thrips caught were generally erratic from week to week, the last major peak occurring during early March 1990.

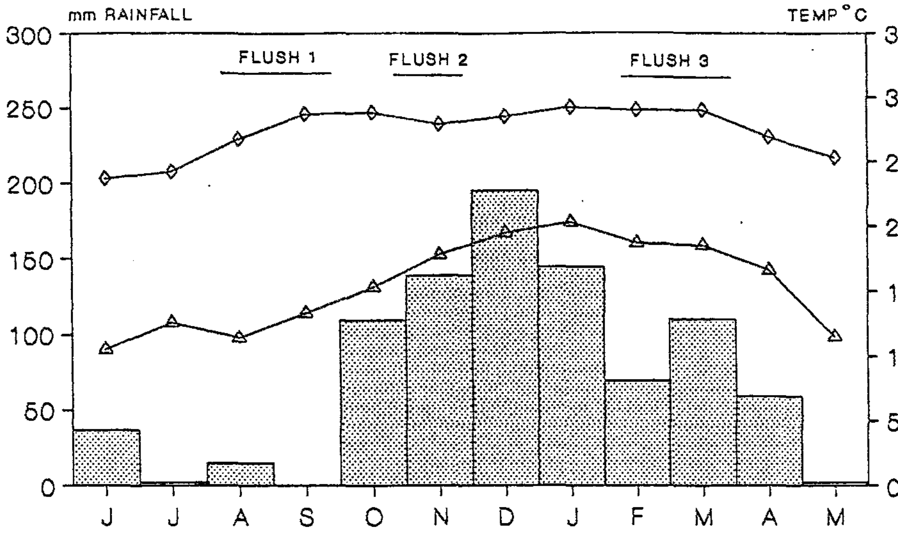


Figure 5.22. Monthly rainfall, mean daily maximum (◇) and minimum temperature (△), and the occurrence of flush periods on the citrus trees, June 1989 - May 1990.

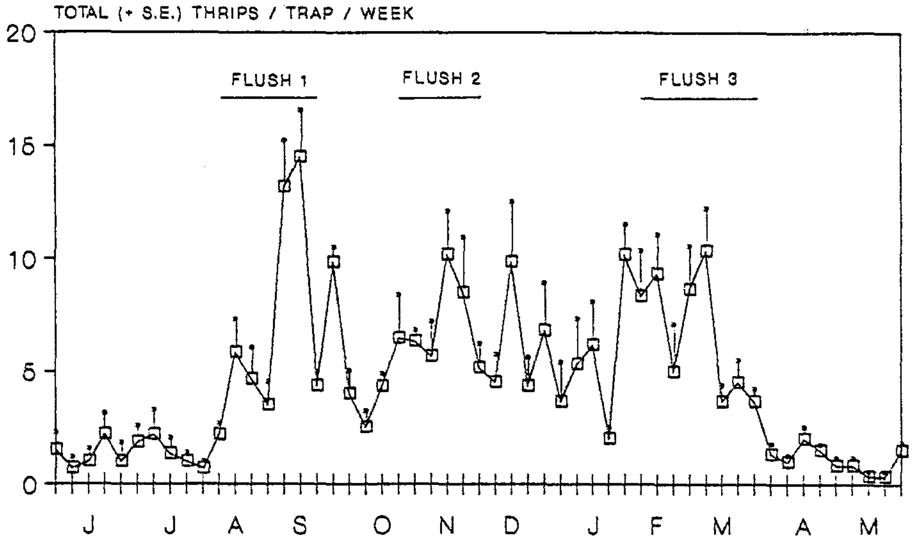


Figure 5.23. Mean (+ standard error of) weekly numbers of adult *S. aurantii* recorded on sticky yellow traps, and the timing of flush periods of the citrus trees, June 1989 to May 1990.

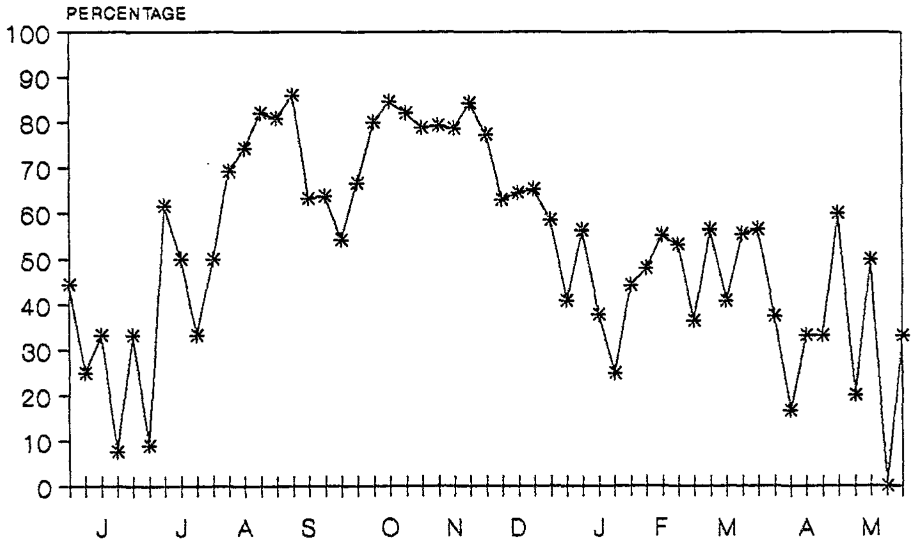


Figure 5.24. Mean weekly percentage of male *S. aurantii* in total recorded on sticky yellow traps, June 1989 to May 1990.

Of the 1443 thrips caught, 881 were males and 562 were females, a significant excess of males overall (table 5.5f). The first main increase in the male percentage occurred in early-August and then rose to nearly 90% in the first half of September (figure 5.24). A significant excess of males was trapped from August to December as in some of the other years. The proportions of males and females did not differ significantly in four of the five months from January onwards.

e) A comparison of male and female *S. aurantii* numbers in relation to citrus tree phenology.

As mentioned previously, the relative proportions of male and female *S. aurantii* on the sticky traps varied considerably, at different times of the year, although an overall 1:1 sex ratio was recorded in the six years sampling period (section 5c above). In particular, sex ratios appeared to be different during and between flush periods (section 5d). During flush periods, a total of 2601 males and 1451 females were trapped, 64.19% and 35.81% respectively. Between flushes a total of 2377 males and 3009 females were trapped, 44.13% and 55.87% respectively (table 5.6 - 5.8). When all the data is combined, the difference in the proportions of the sexes trapped during, and between, flush periods was highly significant ($X^2 = 373.24$, $P < 0.001$). As no observations on tree phenology were made from March - April 1988, (see section 5d above), counts during these months were not included here. For this reason the total of 9,438 citrus thrips is less than the grand total of 10,257 recorded over the continuous period of six years.

Table 5.6 The proportion of male and female *S. aurantii* caught on sticky yellow traps in relation to flushing and non-flushing of citrus, 4th June 1984 - 21st July 1986. N.B. Flush #1 = The flush on which the flowers are borne, i.e. the "spring" flush. Subsequent flushes throughout the growing (not calendar) year are numbered #2, #3 etc. X^2 values refer to a comparison of the proportion of males and females in adjacent time periods.

		S. aurantii					
Time period	Flush	Males	Females	Ratio M:F	% Males	X^2	P
04/06/84 - 16/07/84	-	142	308	0.46	31.56		
						30.70	<0.001 ***
23/07/84 - 17/09/84	#1	141	128	1.10	52.42		
						3.29	0.07
24/09/84 - 01/10/84	-	21	33	0.64	38.89		
						23.93	<0.001 ***
08/10/84 - 12/11/84	#2	96	29	3.31	76.80		
						37.67	<0.001 ***
19/11/84 - 14/01/85	-	27	53	0.51	33.75		
						3.53	0.06
21/01/85 - 18/03/85	#3	57	64	0.89	47.10		
						12.52	<0.001 ***
25/03/85 - 08/07/85	-	21	69	0.31	23.33		
						24.53	<0.001 ***
15/07/85 - 16/09/85	#1	27	12	2.25	69.23		
						0.30	0.58
23/09/85 - 14/10/85	-	15	9	1.67	62.50		
						0.72	0.40
21/10/85 - 02/12/85	#2	54	48	1.13	52.94		
						6.45	0.01 **
09/12/85 - 30/12/85	-	60	102	0.59	37.04		
						13.99	<0.001 ***
06/01/86 - 17/03/86	#3	171	139	1.23	55.16		
						4.01	0.05 *
24/03/86 - 14/04/86	-	123	140	0.89	46.77		
						0.03	0.86
21/04/86 - 16/06/86	#4	152	178	0.85	46.06		
						70.26	<0.001 ***
30/06/86 - 21/07/86	-	60	301	0.20	16.62		

Table 5.7 The proportion of male and female *S. aurantii* caught on sticky yellow traps in relation to flushing and non-flushing of citrus, 30th June 1986 - 25th January 1988. N.B. Flush #1 = The flush on which the flowers are borne, i.e. the "spring" flush. Subsequent flushes throughout the growing (not calendar) year are numbered #2, #3 etc. X^2 values refer to a comparison of the proportion of males and females in adjacent time periods.

		S. aurantii					
Time period	Flush	Males	Females	Ratio M:F	% Males	X^2	P
30/06/86 - 21/07/86	-	60	301	0.20	16.62		
						176.20	<0.001 ***
28/07/86 - 22/09/86	#1	237	127	1.87	65.11		
						0.86	0.35
29/09/86 - 27/10/86	-	265	163	1.63	61.92		
						55.49	<0.001 ***
03/11/86 - 08/12/86	#2	235	32	7.34	88.01		
						0.83	0.36
15/12/86 - 29/12/86	-	325	55	5.91	85.53		
						42.02	<0.001 ***
05/01/87 - 19/01/87	#3	205	113	1.81	64.47		
						84.92	<0.001 ***
26/01/87 - 02/03/87	-	91	232	0.39	28.17		
						15.79	<0.001 ***
09/03/87 - 13/04/87	#4	62	68	0.91	47.69		
						9.73	<0.001 ***
20/04/87 - 27/07/87	-	124	258	0.48	32.46		
						58.13	<0.001 ***
03/08/87 - 21/09/87	#1	97	42	2.30	69.78		
						8.55	<0.001 ***
28/09/87 - 21/12/87	-	411	317	1.30	56.46		
						0.82	0.36
28/12/87 - 25/01/88	#2	77	70	1.10	52.38		

Table 5.8. The proportion of male and female *S. aurantii* caught on sticky yellow traps in relation to flushing and non-flushing of citrus, 2nd May 1988 - 4th June 1990. N.B. Flush #1 = The flush on which the flowers are borne, i.e. the "spring" flush. Subsequent flushes throughout the growing (not calendar) year are numbered #2, #3 etc. X^2 values refer to a comparison of the proportion of males and females in adjacent time periods.

Time period	Flush	*S. aurantii*		Ratio	%	X^2	P
		Males	Females	M:F	Males		
02/05/88 - 01/08/88	-	111	524	0.21	17.48		
						270.40	<0.001 ***
08/08/88 - 19/09/88	#1	171	48	3.60	78.08		
						21.96	<0.001 ***
26/09/88 - 31/10/88	-	176	125	1.40	58.47		
						3.73	0.05 *
07/11/88 - 05/12/88	#2	136	67	2.03	67.00		
						7.31	<0.001 ***
12/12/88 - 26/12/88	-	56	53	1.06	51.38		
						0.28	0.60
02/01/89 - 06/02/89	#3	68	56	1.21	54.83		
						9.27	<0.001 ***
13/02/89 - 20/02/89	-	9	26	0.35	25.71		
						0.76	0.38
27/02/89 - 20/03/89	#4	15	28	0.53	34.88		
						0.24	0.62
27/03/89 - 31/07/89	-	84	132	0.64	38.89		
						70.53	<0.001 ***
07/08/89 - 25/09/89	#1	222	71	3.13	75.77		
						7.72	<0.001 ***
02/10/89 - 16/10/89	-	60	38	1.58	61.22		
						15.06	<0.001 ***
23/10/89 - 27/11/89	#2	202	47	4.30	81.12		
						3.43	0.06
04/12/89 - 29/01/90	-	164	23	7.13	87.70		
						23.92	<0.001 ***
05/02/90 - 26/03/90	#3	176	84	2.09	67.69		
						19.75	<0.001 ***
02/04/90 - 04/06/90	-	32	48	0.67	40.00		
Totals from Tables 5.6, 5.7 & 5.8	Flush	2601	1451	1.79	64.19		
						373.24	<0.001 ***
	Non-flush	2377	3009	0.79	44.13		

There was, in many instances, a significant change in sex ratio ($P < 0.05$) between adjacent (flush and non-flush) periods, but this was not always so (tables 5.6, 5.7 and 5.8). Analysis using the Mann-Whitney paired test supported the hypothesis that more males than females were trapped during flush periods ($n = 20$ pairs, $Z = -3.7$, $P < 0.001$). 16 cases supported the hypothesis and four did not. The four cases in which fewer males than females were trapped occurred relatively late in the growing season, one being the numbers of thrips caught during the third flush of 1984-5, and the others during the fourth flushes of 1985-86, 1986-87 and 1988-89. If we accept that the citrus crop is mainly susceptible to thrips damage up until the end of January, then at the time of year represented by these periods, the fruit would generally be too large for thrips damage to occur, the only exception being the last two weeks at the end of January 1985.

Overall, females were trapped in higher numbers than males during periods when the trees were not flushing (X^2 test, $P < 0.001$). However, using the Mann-Whitney paired test, the hypothesis that non-flush periods were equally likely to have an excess of males or females was not rejected ($n = 21$ pairs, $Z = 1.51$, $P = 0.13$). 13 cases had more females but eight did not. In contrast to the previous paragraph, the eight cases with greater numbers of males all occurred relatively early in the growing season. More males than females were trapped between the first and second flushes (just after petal-fall) in five of the six years studied, the exception being during the 1984-85 growing year. The other cases of between-flush dominance of males occurred between the second and third flushes of three years. At the time of year represented by these time periods, citrus fruit would still have been susceptible to scarring.

To summarize the above results, when all the counts were combined, males were found to predominate in trap catches during flushes. Furthermore, greater numbers of males than females were generally trapped during each individual flush. Flushes during which the sex ratios were not male-biased occurred late in the growing year when the fruit was no longer susceptible to damage. Between flushes, significantly more females than males were trapped overall. However, this result was less clear-cut and during several inter-flush periods less females than males were trapped. Sex ratios during inter-flush periods were therefore less consistent than during flush periods. However, females were in the minority between flushes only when citrus fruit was still vulnerable to thrips damage.

f) Effects of rainfall and temperature on thrips numbers.

The degree of economic damage caused by a pest is likely to be in proportion to its population level. Climate may be an important factor governing the population size of a pest. In the following section, the direct and indirect effects of the weather on fluctuations in *S. aurantii* populations are examined.

i) Direct effects

The relationship between weather conditions each year and the numbers of thrips that were trapped was examined for the period June 1984 - May 1990. Total thrips numbers trapped in each month, as well as those of males and females separately, were correlated with monthly mean daily maximum and minimum temperatures and total rainfall. Out of the total of 108 regressions (3 weather factors x 3 categories of thrips - total, male, and female, x 12 months) only one showed significance, a positive correlation between female thrips and minimum temperature in November (P = 0.03, table 5.9). Re-analysis after combination of the data into three-month seasonal periods again produced no significant results (table 5.10). Given the large number of correlation analyses carried out, even the one significant result may be a type I error (Levin 1981). If the direct effects of weather at that time were important in influencing the number of thrips trapped in any particular month at Letaba one would expect a number of the correlations to be significant, but the results do not support this. It can therefore be concluded that the monthly and seasonal numbers of thrips trapped are independent of weather factors operating at those times.

ii) Indirect effects

In southern Africa, where diapause by *S. aurantii* appears to be absent, factors contributing to increased survival of the overwintering generations may contribute to the likelihood of economic damage on young fruitlets the following Spring. With this in mind, previous weather conditions were correlated with thrips numbers. However, rainfall, maximum or minimum temperature during winter were again found not to be significantly correlated with citrus thrips numbers in spring (table 5.11).

It might also be expected that high numbers of thrips trapped in late autumn would lead to high numbers of thrips during early winter. However, this was not so and the regression of thrips

Table 5.9 Regression analysis of total, male, and female *S. aurantii* trapped against total rainfall, mean maximum-, and mean minimum daily temperatures. I. Monthly sampling intervals.

		Rainfall			Maximum temp.			Minimum temp.		
Month	Citrus thrips	F ratio	R^2 %	P	F ratio	R^2 %	P	F ratio	R^2 %	P
June	total	4.92	55.13	0.09	0.32	7.40	0.60	0.29	6.85	0.62
	males	5.99	60.00	0.07	0.47	10.42	0.53	0.13	3.04	0.74
	females	4.21	51.30	0.11	0.26	6.06	0.64	0.38	8.61	0.57
July	total	0.13	3.24	0.73	0.11	2.90	0.75	0.60	13.16	0.48
	males	0.84	17.41	0.41	0.57	12.55	0.49	0.18	4.30	0.69
	females	0.05	1.32	0.83	0.06	1.43	0.82	0.76	15.97	0.43
Aug	total	0.24	5.59	0.65	0.05	1.29	0.83	0.90	18.41	0.40
	males	<0.01	0.07	0.96	0.02	0.38	0.91	0.03	0.74	0.87
	females	0.72	15.26	0.44	0.08	1.84	0.80	3.21	44.55	0.15
Sept	total	0.02	0.40	0.91	1.76	30.59	0.25	0.63	13.60	0.47
	males	0.07	1.75	0.80	1.76	30.59	0.25	0.96	19.41	0.38
	females	0.05	1.34	0.83	1.27	24.06	0.32	0.09	2.21	0.78
Oct	total	3.16	44.12	0.15	0.82	16.96	0.42	1.60	28.70	0.27
	males	2.84	41.51	0.17	0.68	14.55	0.46	1.54	27.80	0.28
	females	3.46	46.61	0.14	1.03	20.45	0.37	1.62	28.84	0.27
Nov	total	0.10	2.49	0.77	0.49	10.91	0.52	0.95	19.24	0.38
	males	2.52	38.67	0.19	0.16	3.76	0.71	0.15	3.73	0.71
	females	1.10	21.55	0.35	1.36	25.32	0.31	11.64	74.43	0.03
Dec	total	0.21	5.10	0.67	0.25	5.85	0.64	0.07	1.68	0.81
	males	0.12	2.99	0.74	0.09	2.19	0.78	0.01	0.27	0.92
	females	0.23	5.40	0.66	0.74	15.52	0.44	0.45	10.10	0.54
Jan	total	<0.01	0.05	0.97	0.19	4.43	0.69	1.11	21.66	0.35
	males	<0.01	0.10	0.95	0.07	1.69	0.81	0.51	11.34	0.51
	females	0.00	0.01	0.99	0.48	10.77	0.52	2.82	41.42	0.17
Feb	total	0.01	0.35	0.91	0.62	13.50	0.47	0.63	13.66	0.47
	males	0.01	0.18	0.94	0.04	0.91	0.86	0.04	0.90	0.86
	females	0.02	0.38	0.91	1.04	20.68	0.36	1.64	29.02	0.27
Mar	total	0.66	14.22	0.46	0.17	4.10	0.70	4.63	53.65	0.10
	males	0.27	6.27	0.63	0.07	1.64	0.81	3.15	44.06	0.15
	females	1.16	22.49	0.34	0.28	6.58	0.62	5.77	59.05	0.07
Apr	total	0.50	11.10	0.52	1.49	27.18	0.29	2.32	36.68	0.21
	males	0.26	30.29	0.26	3.32	45.33	0.14	3.56	47.29	0.13
	females	0.11	2.71	0.76	0.62	13.40	0.48	1.19	23.00	0.34
May	total	1.02	20.32	0.36	1.23	23.45	0.33	0.01	0.27	0.92
	males	0.73	15.46	0.44	1.46	26.71	0.29	0.02	0.57	0.89
	females	0.82	17.04	0.42	0.79	16.54	0.42	0.04	0.88	0.86

Table 5.10 Regression analysis of total, male, and female *S. aurantii* trapped against total rainfall (mm), mean maximum, and minimum daily temperatures. II. 3-month sampling periods.

		Rainfall			Maximum temp. °C			Minimum temp. °C		
SEASON		F ratio	R^2 (%)	P	F ratio	R^2 (%)	P	F ratio	R^2 (%)	P
Winter - June, July, & Aug.	total	0.19	4.61	0.68	0.10	2.50	0.76	0.10	2.38	0.77
	males	1.53	27.73	0.28	<0.01	0.08	0.96	0.16	3.79	0.71
	females	0.04	0.84	0.86	0.20	4.87	0.67	0.33	7.70	0.59
Spring - Sept, Oct, & Nov.	total	0.08	2.58	0.80	0.56	15.79	0.51	0.01	0.19	0.95
	males	0.21	6.45	0.68	0.17	5.41	0.71	0.36	10.63	0.59
	females	0.03	1.14	0.86	0.51	14.63	0.53	0.02	0.49	0.91
Summer - Dec, Jan, & Feb.	total	3.60	47.61	0.13	5.60	58.49	0.08	0.00	0.05	0.97
	males	1.94	32.64	0.24	3.70	48.11	0.13	0.34	7.86	0.59
	females	4.36	52.15	0.11	4.22	51.33	0.11	0.53	11.72	0.51
Autumn - Mar, April, & May.	total	5.12	56.12	0.09	1.13	1.13	0.35	0.70	14.95	0.45
	males	2.65	39.88	0.18	4.19	51.17	0.11	0.14	3.44	0.72
	females	4.14	50.83	0.11	0.36	8.16	0.58	0.95	19.25	0.38

Table 5.11 Regression analysis of total, male, and female *S. aurantii* trapped in spring against total rainfall, maximum, and minimum daily temperatures recorded the previous winter.

	WINTER WEATHER								
	Rainfall			Maximum temp. °C			Minimum temp. °C		
Citrus thrips in spring	F ratio	R^2 (%)	P	F ratio	R^2 (%)	P	F ratio	R^2 (%)	P
total	0.03	0.28	0.85	0.24	7.50	0.66	0.08	2.57	0.80
males	0.05	0.72	0.83	0.62	17.16	0.49	0.01	0.39	0.92
females	0.01	0.04	0.97	0.06	1.81	0.83	0.51	14.63	0.53

Table 5.12 Regression of total rainfall (mm) in March and April against *S. aurantii* numbers trapped in a) winter (JJA) and b) spring (SON).

	RAINFALL IN MARCH AND APRIL						
a) Citrus thrips in winter	F ratio	R^2 (%)	P	b) Citrus thrips in spring	F ratio	R^2 (%)	P
total	2.45	38.01	0.19		0.23	5.52	0.65
males	0.74	15.60	0.44		0.18	4.39	0.69
females	3.35	45.61	0.14		0.31	7.10	0.61

numbers caught in March and April, (the two months within which the autumn peak usually occurred), against those recorded in June and July showed no significant result when considering either total thrips, or males and females separately (P = 0.63, 0.50, and 0.72 respectively).

However, regressions of total, and male, thrips trapped in winter (June, July and August), against those trapped in the subsequent spring (September, October and November) showed a significant (non-linear) positive correlation (figures 5.25 and 5.26). The female numbers were not significantly correlated, however (figure 5.27). In the regressions relating to spring numbers of thrips, the result for 1984 was omitted due to a catastrophic hailstorm which devastated the experimental orchard and seemed to prevent the normal build-up of thrips in spring (see section 5d above).

From mid-summer onwards, rainfall appeared to have a particularly strong influence on the patterns of tree flushing. A high degree of fluctuation in the level of winter populations of *S. aurantii* was also recorded on the traps. At times of the year when fruit is not available as a food source, either by being too large (the skin presumably being too tough for the penetration of the mouthparts), or before the new fruitlets are exposed on the tree at petal-fall, rainfall might be expected to be an important factor for thrips populations through its promotion of flush or out-of-season fruit and hence providing a food source on which citrus thrips can overwinter. Referring back to figure 5.1 and table 5.1, it can be seen that the rainfall means recorded in January and February were very low (87.4 and 114.0mm) over the study period in comparison to the long-term means (146.0 and

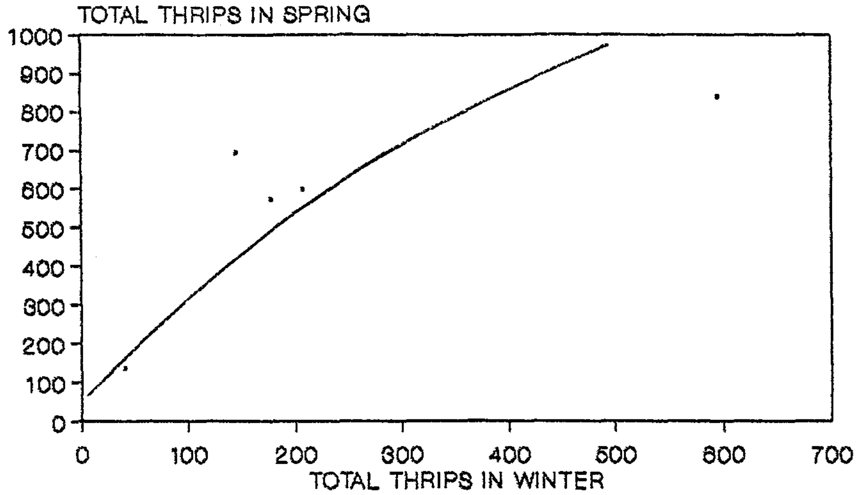


Figure 5.25. The relationship between the total (male and female) numbers of *S. aurantii* recorded on yellow traps in winter (June, July & August) and spring (September, October & November). R^2 = 79.83%, F-Ratio = 11.87, y = 2.68x^0.68, P = 0.04.

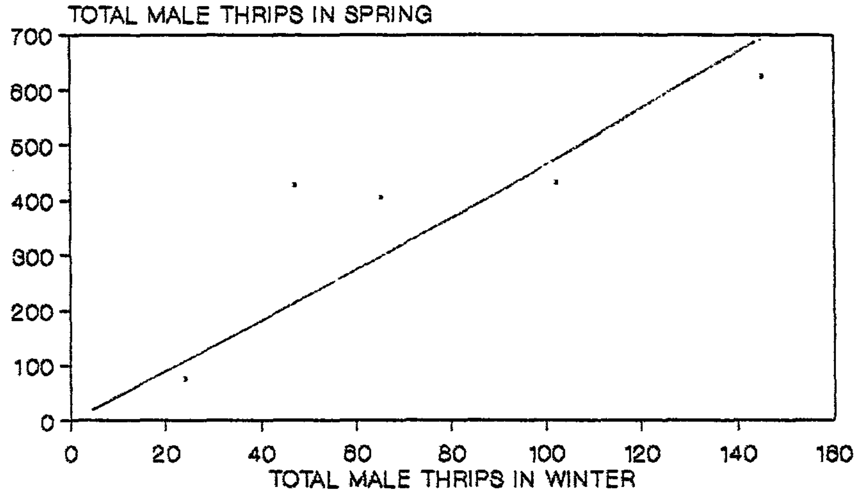


Figure 5.26. The relationship between the total numbers of male *S. aurantii* recorded on yellow traps in winter (June, July & August) and spring (September, October & November). R^2 = 75.8%, F-Ratio = 9.39, y = 1.41x^1.05, P = 0.05.

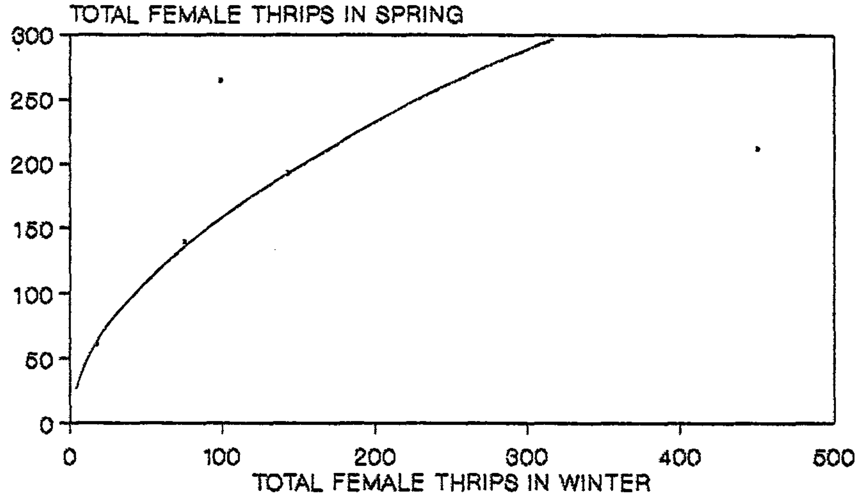


Figure 5.27. The relationship between the total numbers of female *S. aurantii* recorded on yellow traps in winter (June, July & August) and spring (September, October & November). R^2 = 67.1%, F-Ratio = 6.11, y = 3.22x^1.68, P = 0.09.

148.8mm). The following two months showed a mean rainfall slightly above that of the long-term. The low May rainfall was insignificant compared to the previous four months. Attention was therefore focussed on the rainfall of the first four months of the year to see if this climatic factor was in any way correlated with thrips numbers during the following winter and spring.

Firstly, considering the rainfall in March and April, this varied from a total of 75.3mm in 1989 to 230.1mm in 1988. A regression of thrips numbers in winter (June, July and August) against the total rainfall in March and April did not give a significant result with either total thrips, or when considering males and females alone (table 5.12). In other words, the occurrence of high rainfall during March and April did not, on it's own, indirectly lead to increased numbers of thrips during the following winter. Not surprisingly, rainfall during this period was also not significantly correlated with thrips numbers the following spring.

A relative rainfall index for each year was then derived by dividing the total rainfall for March and April by that of January and February. An index of one meant that the total rainfall in each pair of months was equal. In this way the relationship between mid- to late summer, and early to mid-autumn, rainfall was calculated. Index values ranged from 3.31 in 1984 to 0.31 in 1985 (table 5.13). This rainfall index was then correlated with numbers of citrus thrips trapped during the following winter. Total thrips, and males and females separately, were all significantly positively correlated (figures 5.28, 5.29 and 5.30). Thus the years where the occurrence of high rainfall during the autumn months of March and April had followed

Table 5.13 Derivation of the rainfall index (relating March + April rainfall to January + February rainfall), and the total numbers of *S. aurantii* trapped in a) the following winter (June, July & August), and; b) the following spring (September, October & November).

	Rainfall (mm)			*S. aurantii* in winter			*S. aurantii* in spring		
Year	March + April	Jan + Feb	Index (MA/JF)	Total	Males	Females	Total	Males	Females
84	208.0	62.8	3.31	591	201	390	276	183	93
85	124.6	397.7	0.31	41	24	17	134	74	60
86	214.0	115.5	1.85	595	145	450	835	624	211
87	151.1	166.6	0.91	145	47	98	690	426	264
88	230.1	308.1	0.75	207	65	142	596	404	192
89	75.3	145.2	0.52	177	102	75	570	431	139

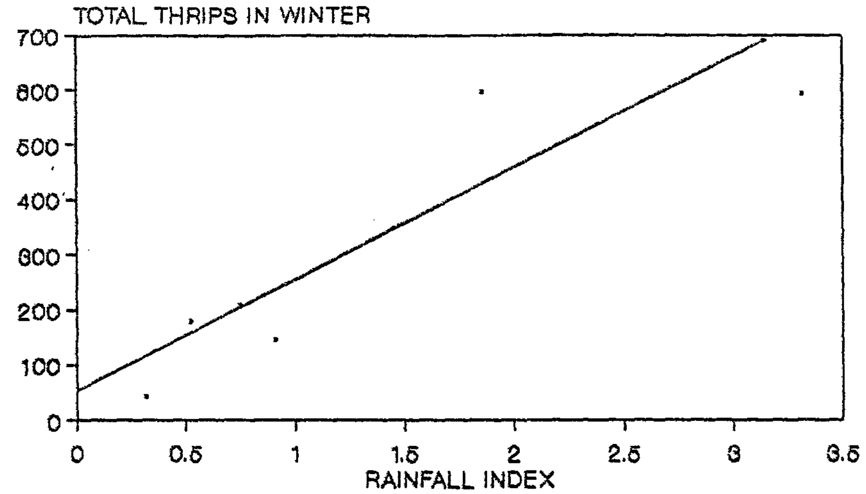


Figure 5.28. The relationship between the Rainfall Index (as defined in the text) and the total (male and female) numbers of *S. aurantii* recorded on yellow traps in winter. R^2 = 80.14%, F-Ratio = 16.14, y = 189.6x + 50.9, P = 0.02.

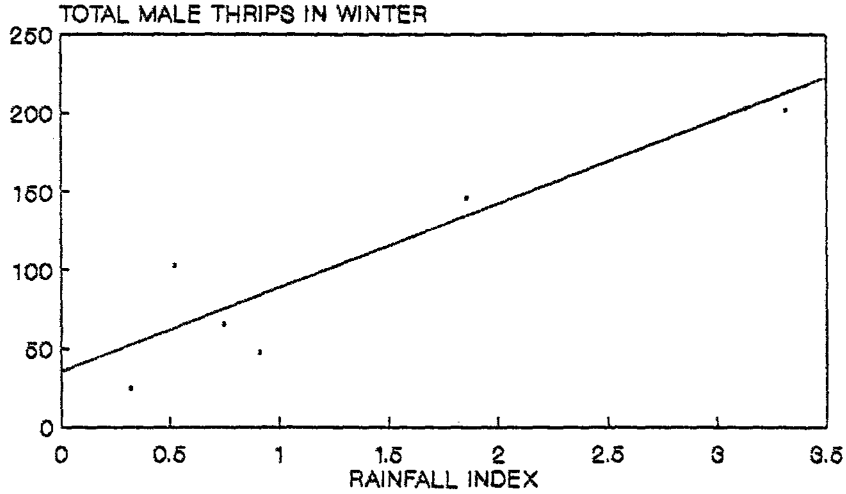


Figure 5.29. The relationship between the Rainfall Index (as defined in the text) and the total numbers of male *S. aurantii* recorded on yellow traps in winter. R^2 = 82.8%, F-Ratio = 19.27, y = 53.4x + 29.2, P = 0.01.

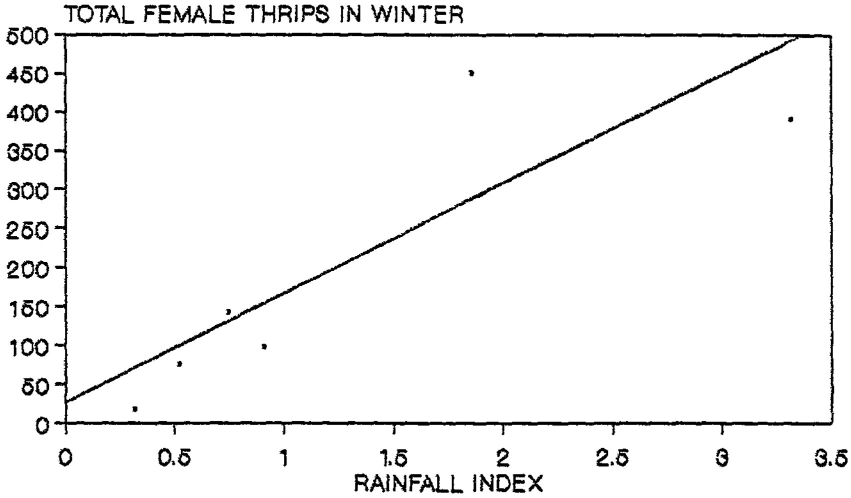


Figure 5.30. The relationship between the Rainfall Index (as defined in the text) and the total numbers of female *S. aurantii* recorded on yellow traps in winter. R^2 = 73.34%, F-Ratio = 11.01, y = 136.2x + 21.7, P = 0.03.

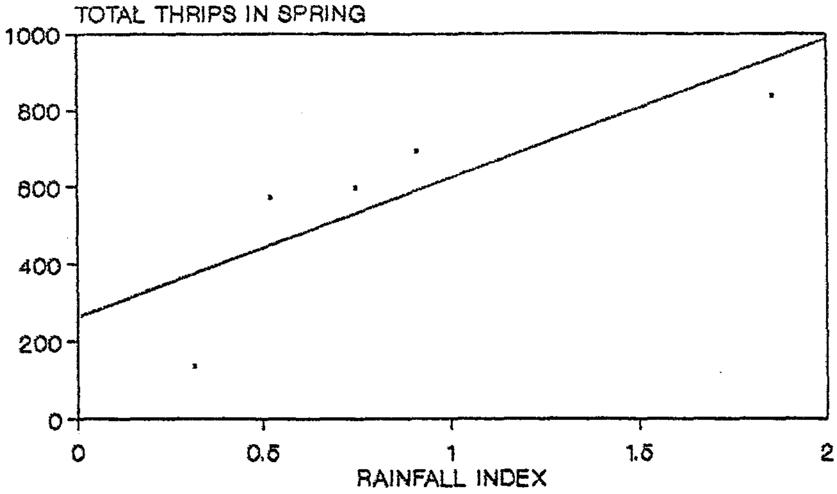


Figure 5.31. The relationship between the Rainfall Index (as defined in the text) and the total (male and female) numbers of *S. aurantii* recorded on yellow traps in spring. R^2 = 65.72%, F-Ratio = 5.75, y = 357.9x + 254.4, P = 0.1.

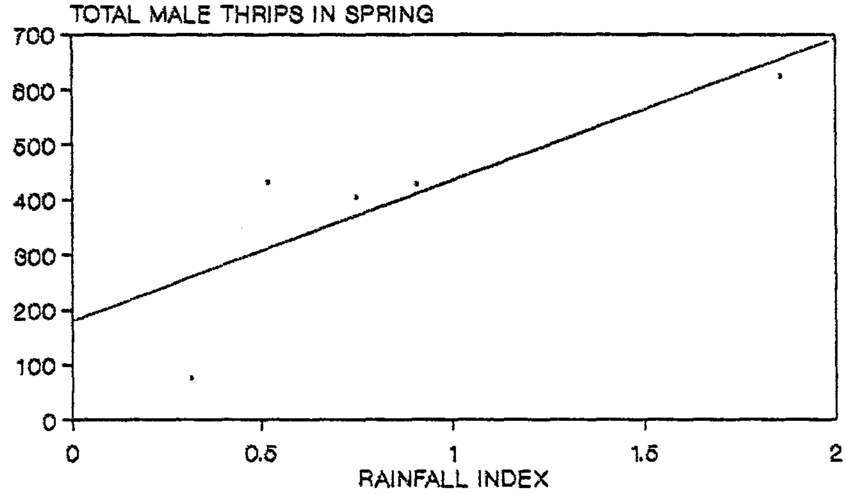


Figure 5.32. The relationship between the Rainfall Index (as defined in the text) and the total numbers of male *S. aurantii* recorded on yellow traps in spring. R^2 = 68.85%, F-Ratio = 6.63, y = 277.3x + 151.1, P = 0.08.

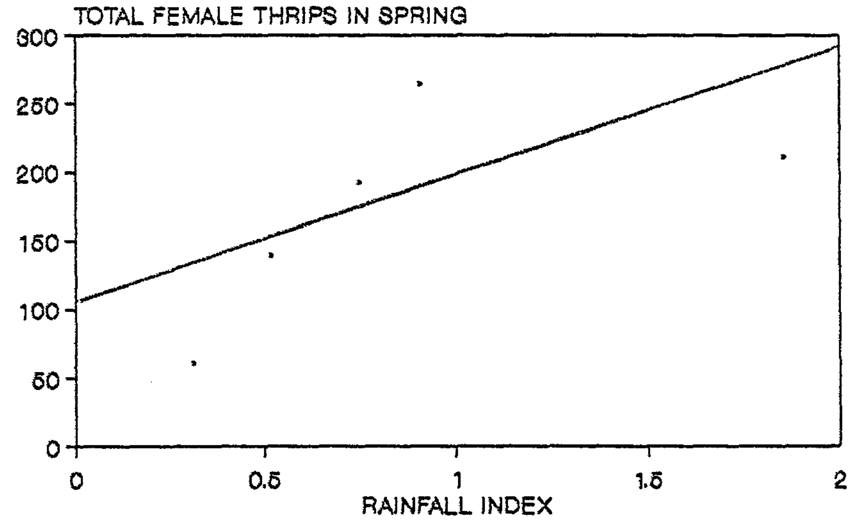


Figure 5.33. The relationship between the Rainfall Index (as defined in the text) and the total numbers of female *S. aurantii* recorded on yellow traps in spring. R^2 = 38.17%, F-Ratio = 1.85, y = 80.6x + 103.3, P = 0.27.

a dry late summer (January and February) were those where high numbers of overwintering citrus thrips were recorded. This pattern of rainfall was associated with the stimulation of growth flushes late in autumn and with the setting of out-of-season fruit, and this was presumably the reason for the observed effects. (section 5d).

When the regressions were repeated using the thrips numbers rather later in spring (September, October and November), the same general pattern was evident, but the results failed to reach significance at the 5% level (tables 5.31, 5.32 & 5.33). This was despite significant relationships between the numbers of thrips trapped in winter and the following spring.

DISCUSSION

Rainfall, irrigation practices and variation in the flushing patterns of the citrus trees.

Catling (1970) recorded three citrus flush periods at Letaba: August to September; December to January; and February to March. However, the results of the present study over a number of years showed that, particularly in autumn, the pattern of flushes can vary considerably from the above.

As regards the first flush of the growing season (#1), this appeared at approximately the same time each year, in the latter half of July or in early August. This is because at Letaba, rainfall is on average very low during the months of May to September, and stimulation of the first flush of the growing season on which the flower buds (and subsequently fruit) are borne is reliant upon irrigation. As a standard practice, this is applied towards the end of June or early July each year. In most other citrus-growing areas of the world, irrigation is also essential to maintain high citrus yields, thereby overcoming the lack, or unreliability, of rainfall (Marsh 1973).

The second flush of the season was far more variable in the timing of it's appearance, from as early as the second week of October in 1984 to as late as the end of December in 1987. Whatever its timing, the appearance of this flush was within the period when severe thrips damage can be caused on citrus fruit. In other words when the fruit was still a highly attractive food source. The variation in the timing of the second flush period was therefore not necessarily critical for the thrips population, because there was other food available in the form of fruit. However, from personal observations over a number of years, it was clear that the new shoots of the second flush (and indeed any flush) become readily infested by citrus thrips, whether fruit is also available or not. New plant growth in general is known to be particularly nutritious (Scriber & Slansky 1981) and it seems that, in the case of citrus, *S. aurantii* is attracted, to a certain extent, away from the fruit onto new flush.

The long-term monthly rainfall averages at Letaba increased progressively from June until February, and even in March over 100mm of rain was usually recorded. However, over the experimental period, the mean monthly rainfall of January and February was much lower than the long-term mean and in 1984 and 1986 these months were extremely dry. Where this was followed by comparatively high rainfall in the following two months, a fourth growth flush and out-of-season fruit was stimulated, offering food sources for *S. aurantii* which were not normally available during late autumn and winter.

The influence of rainfall on citrus cultivation at Letaba therefore becomes greater as the growing year progresses. The effect of late rainfall patterns is further enhanced by two cultural practices in navel orchards. Firstly, from December onwards until harvesting in April, irrigation of this cultivar is reduced and may even be stopped. This is done in order to limit the development of oversized fruit,which usually have a poor internal quality, are unsuitable for export, and consequently result in an economic loss to the estate. Over this period, the trees are therefore placed under moisture stress, which inhibits the production of vegetative growth or flush (Furr & Taylor 1939).

A further requirement of standard citrus cultivation is that a period of tree dormancy must occur after harvesting in order to achieve satisfactory flower induction, and hence blossoming,the following spring (Reuther 1973). This can be achieved in two ways, depending upon the climate of a particular area. In production areas where the mean winter temperature is below 13°C, cold-induced dormancy can be achieved (Green et al 1975). However, in many tropical or subtropical areas, of which the Lowveld (in which Letaba is situated) is one, temperatures remain above this threshold throughout the year and so cold dormancy cannot be induced. Tree dormancy must therefore be brought about by subjecting them to moisture stress. In areas like Letaba, where winter rainfall is usually low, the trees are usually maintained under sustained moisture stress after harvesting (in the absence of high rainfall), by limiting or withholding irrigation. This acts as a substitute for chilling in inducing dormancy (Cassin et al. 1969).

The two cultural practices outlined above both promote moisture stress. As a result of this, the citrus trees at Letaba are particularly inclined to flush in late autumn if unusually late rainfall occurs after a dry January and February.

Citrus thrips populations in relation to flushes, rainfall and temperature.

The results from 1984 - 1990 show that, in the absence of chemical sprays, there was for all practical purposes always a resident population of citrus thrips adults within the citrus orchard. During the six-year survey, there were only two weeks, (those ending 5/8/85 and 1/8/88), when no adult *S. aurantii* were recorded. This differs significantly from the results of the only comparable study, on Reunion Island in the Indian Ocean. There, using the same method of trapping, *S. aurantii* could not be traced at all in citrus orchards from March until the end of July (Quilici et al. 1988).

Thrips numbers varied considerably both within, and between, years. When the total number of thrips caught per month is considered, the spring and summer months of September to February yielded the highest numbers of thrips. However, it is interesting to note that despite widely-differing between-month means the variation within-months from year to year was such that overall there were no significant differences between any of the months. *S. aurantii* numbers in each month are therefore highly unpredictable from year to year.

No long-term trends in thrips numbers were evident, with years when thrips were relatively scarce sometimes being followed by years of abundance and vice-versa. Within years, most peaks of *S. aurantii* adults on the traps occurred as leaves of a particular growth flush were hardening off. This phenomenon is not uncommon in thrips species which feed on soft, newly-formed plant tissue (Lewis 1973). In such species, the time at which second instar larvae mature and drop to the ground to pupate is closely correlated with the hardening of the plant tissue on which it feeds. On citrus, this is especially significant in spring because the first subsequent mass emergence of *S. aurantii* adults therefore coincided with the end of flowering. This meant that numerous adult thrips were usually present as the small fruitlets become exposed after petal-fall in the latter half of September.

Development of *S. aurantii* is not arrested in winter, presumably due to the mild conditions experienced in southern Africa (Bedford 1943). This results in overlapping generations. However, the onset of a new flush period after some weeks when little or no new growth was available might be expected to synchronize initial egg-laying to a great extent. The so-called "spring" flush usually appears at Letaba (during winter) late in July or early in August. Bearing in mind that the winter generation time of *S. aurantii* is approximately six weeks (Bedford 1943), the adults which initially infest the fruit soon after petal-fall will be from the first generation which developed as larvae on the first flush of the growing season. Control measures which are applied after petal-fall are therefore intended to prevent the laying of eggs by these adults and the subsequent establishment of second generation larvae on the fruit. This is analogous to the situation in California involving *S. citri*. However, *S. citri* experiences a relatively severe winter and overwinters almostly exclusively in the egg stage in leaves which have hardened off (McGregor 1944). With the onset of warmer weather in spring, the larvae hatch from the old leaves and wood and move to the new growth. In California, control measures are therefore only applied against the next (second) generation which infests the fruitlets as they form after petal-fall.

The results presented here show that the weather at Letaba had no great influence on the numbers of adult citrus thrips trapped at that time. In contrast, rainfall through its manipulation of the timing of flush periods during late summer and autumn had a significant (but indirect) influence on the number of thrips which survived the winter. Thus, high numbers of thrips in late autumn did not necessarily lead to high winter survival because, in most years, out-of-season fruit was absent and the last growth flush hardened off relatively early. However, in years when the combined rainfall of March and April was high compared to that of January and February, the conditions were conducive to the production of a late growth flush and out-of-season fruit, which resulted in high numbers of thrips during winter.

It should be remembered that the growth flush (#1) which bears the flowers for the new fruit crop is stimulated during late winter by irrigation and begins to show at the end of July or the beginning of August. Citrus thrips therfore only have to survive two months of winter before an abundant food supply is available to them in any year. The winter climate of Letaba is not sufficiently harsh to prevent increases of citrus thrips numbers to high levels if food is available. The presence of a food source during June and July was therefore the most important factor governing thrips numbers in spring, when they become economically important.

Sex ratios

The overall 1:1 sex ratio of *S. aurantii* recorded on the traps is unusual in the light of what is known about the Order Thysanoptera as a whole, and what has been recorded about *S.aurantii* specifically. Females typically predominate in thrips populations. In species where males are unknown or extremely rare e.g. *Heliothrips haemorrhoidalis*, reproduction is by the process of thelotoky or automictic parthenogenesis, with only diploid females being produced (Suomalainen 1962). In species where males are known (such as *S.aurantii*), fertilized eggs give rise to diploid females by sexual reproduction, whereas unfertilized eggs give rise to haploid males parthenogenetically through the process of arrhenotoky; this situation being termed haplodiploidy (Lewis 1973). In some species which are chiefly thelotokous e.g. *Thrips tabaci*, males may nonetheless be found in certain parts of the world, where arrhenotoky may be locally important (Kendall and Capinera 1990).

As regards *S.aurantii*, both Hall (1930) and Bedford (1943) observed the hatching of larvae from eggs layed by virgin females, confirming that parthenogenesis did take place. However, Hall (1930) considered males to be very rare, and did not observe any copulation of *S.aurantii*. This would have indicated that reproduction was normally thelotokous. In contrast, Bedford (1943) found males to be common, observed copulation between the two sexes and, from a (field) collection of over a thousand specimens, found 23% were males and 77% females. In addition, the original description of *S.aurantii* was based on the examination of 440 (field-collected) specimens, of which 23.6% were males and 77.4% were females (Faure 1929). These results, as well as the fact that males were common on the traps in the present study, indicate that at Letaba *S.aurantii* does not reproduce by thelotoky, but by arrhenotoky. The sex ratios recorded on the traps in June and July are very similar to those found by Faure (1929) and Bedford (1943). However, those of all the other months show a much higher percentage of males than one might expect from their results. Furthermore, significantly greater numbers of males than females were caught during periods when the trees were flushing, and from August, when the spring flush usually appeared, until December, significantly greater numbers of males than females were caught, regardless of whether the trees were flushing or not. From petal-fall until the end of December is considered to be most the critical period for economic damage caused by citrus thrips (Bedford 1943, Samways 1986), and this period therefore coincides with high frequencies of males on the traps. However, this does not necessarily mean that the true sex ratio is male-biased at this time.

The apparent sex ratio of a population may vary due to a number of factors. The true sex ratio is a measure of the sexes of the eggs which are laid. From then on, any mortality factor acting differentially on the sexes will cause a shift in the sex ratio of the population. This may include differences in larval mortality and adult longevity.

However, distorted sex ratios may also result from "errors" in sampling, due to selective trapping of one or other sex. To take an extreme example, when using coloured traps to attract and catch thrips, spurious sex ratios can result if one or other sex is flightless, as in *Limothrips cerealium* males (Lewis 1959a). This is clearly not the case in *S.aurantii*. However even in insect species where both sexes are fully winged, the response of one or other sex to a coloured trap can vary (Southwood 1978). Examples include the preferential attraction of *Stenothrips gramimum* Uzel males to white water traps (Lewis 1961), and the disproportionate catches of male *Frankliniella occidentalis* on white sticky traps at certain heights within greenhouses (Gillespie & Vernon 1990).

It is therefore possible that the sex ratios recorded on the sticky traps during the present study were not representative of the true adult population sex ratios in the citrus orchard. This possibility is examined further in the next chapter.

6. AN EVALUATION OF "DISPERSAL/EMERGENCE" TRAPS AS A MEANS OF MONITORING *S. aurantii* POPULATIONS

INTRODUCTION

Pupation in the soil beneath the host plant is a characteristic of many thrips species including *Isoneurothrips australis* Bagnall (Laughlin 1970), *Frankliniella parvula* Hood (Harrison 1963), and others (Varatharajan and Daniel 1984). This behaviour is also shown by the citrus thrips *S. citri* and *S. aurantii*, although it is known that a proportion of the larvae of both species pupate in the tree (Grout et al. 1986, personal observations).

In California, in addition to scouting for infested fruit, monitoring of *S. citri* is aided by two methods of trapping. Use is made of yellow sticky traps which trap flying adults (Moreno et al 1984, and chapter 5), and also "Dispersal / Emergence" or D/E traps (Reed & Rich 1975, Tanigoshi & Moreno 1981). The latter sample mature thrips larvae as they fall (disperse) to the ground to pupate and young adults emerging from the soil. In southern Africa yellow sticky traps are used routinely as an aid to monitoring *S. aurantii* and economic thresholds have been established (Samways 1986, Grout & Richards 1990). In contrast, D/E traps have not previously been evaluated.

Early observations on the pupation of *S. aurantii* indicated that this only took place within the citrus tree (Hall 1930). If this was so then the D/E trap would be of no use whatsoever. Conversely, the later observations of Bedford (1943) showed that pupation took place in the ground, suggesting that the D/E trap may be suitable for monitoring *S. aurantii* in southern Africa.

Personal observations suggest that while pupae of *S. aurantii* can be found under the calyx of oranges, this appears to only occur very rarely.

An evaluation of the D/E trap for *S. aurantii* population monitoring was carried out in the experimental orchard at Letaba. The initial aim of this study was to see if this trap was practical for use in an orchard situation, and a second aim was to compare the resulting estimates of thrips population changes with those obtained from sticky yellow traps. A preliminary experiment was required to determine the optimal position for the traps under the citrus trees. Previously, Reed & Rich (1975) in California found that most *S. citri* were caught on D/E traps at a distance of 30cm from the tree trunk. Numbers caught declined further out towards the drip-line of the tree. They also found that greater numbers of citrus thrips were caught in the northern quadrant.

At Letaba, having as far as possible established the optimal position for D/E traps in relation to the tree trunks, a long term population monitoring experiment was then carried out. This was run continuously from September 1986 to December 1987, and from June to December 1988.

METHODS

The construction of the D/E traps is described in chapter 2. In order to determine their optimal positioning, four traps were placed on the ground around trees at the four cardinal compass points at the following four distances from the trunk, 30cm, 60cm, 90cm, and 120cm. This made a total of 16 traps per tree. The traps were left in place for a week after which time the perspex squares were removed and covered with Gladwrap ^{R} and taken to the laboratory for examination. Three trees were used and the experiment was repeated over three separate weeks during May and June 1986, giving a total of 9 replicates of each trap position and a total of 144 counts.

Having established suitable trap positions in terms of distance from the trunk and orientation (see results section), four D/E traps were set up beneath each of six trees within the experimental orchard, making a total of 24 traps in all. These were placed at 90° from each other around the cardinal compass points at a distance of 30cm from the trunk. The trapping surface was replaced each week. Trapped larvae, emerging adults of *S. aurantii* and also any other adult thrips, were recorded. The sexes of all the *S. aurantii* adults caught were also noted. As the perspex plate prevented the larvae from reaching the ground (an example of destructive sampling), it was also necessary to change the position of each trap weekly in order to enable the monitoring of emerging adults to continue. Each trap was therefore moved to an adjacent patch of ground every week (within the same quadrant) and then the following week returned to its original position.

RESULTS

Handling of the traps

A number of minor problems were associated with the use of these traps. Firstly, during the blossoming period the top surface of the perspex plate was often covered with fallen petals making it difficult to see all the trapped larvae. This drawback was also mentioned by Tanigoshi & Moreno (1981) whose solution was to turn the perspex plate upside down and count the larvae looking through the bottom of the transparent plate. In practice at Letaba this did not prove to be an ideal solution and great care had to be taken that all larvae were discovered amongst the fallen petals. Nonetheless, emerged adult thrips were easily counted when examining the plate from the underside.

A further problem arose during periods of heavy rain when water and mud would splash up from the ground causing the top surface of the perspex plate to be covered with a fine silt. Again great care had to be taken to detect all the trapped larvae.

Identification of larvae

It was noticeable that the dead larvae of all species, which were very delicate, tended to swell or shrink according to the weather conditions during which the trapping was carried out. Wet weather tended to cause the larvae to swell and become paler in colour, whereas dry weather caused the opposite effects. In certain species this affected the ease of larval identification. This problem did not arise with larvae of *Haplothrips* spp., which had red transverse bands across the body and were readily distinguishable from *S. aurantii*. However, because living larvae of *T. tenellus* are also yellowish-white in colour and only a little larger than those of *S. aurantii*, the possibility existed of confusion between the larvae of the two species on the traps, especially if one considers the effects of humidity on the size and colour of the trapped specimens.

Identification of adults

Newly-emerged (teneral) adults of some insect species differ significantly in colour from mature specimens. For example, the young adult citrus psylla *T. erytreae* is pale green and matures to a dark brown colour (Catling 1967). As regards *S. aurantii*, the colour of the adults caught on the underside of the perspex plate did not differ from those sampled from the tree or caught on yellow traps. The abdominal stripes of both sexes were visible as were the black drepana on the hind femur of the males. Adults of *S. aurantii* could therefore be readily distinguished from those of other species, and the sexes were also distinguishable.

Trap position

The numbers of larval and adult *S. aurantii* caught in the preliminary experiments to investigate optimum trap positions are shown in tables 6.1a-c. Statistical analyses (using the Mann-Whitney paired sign test) were carried out to determine if there was significant variation in the numbers of thrips caught from tree to tree in the same week, and from week to week on the same tree (table 6.2). Firstly considering tree 1, the number of thrips caught in each of the three weeks did not differ significantly, probably due to the low numbers caught during the whole period. With trees 2 and 3, the week to week numbers differed significantly (table 6.2a).

The generally low numbers caught in week 1 contributed to the lack of significance between trees during that period (table 6.2b). Four out the six other comparisons indicated significance. It is therefore apparent that, in the weeks when reasonable numbers of thrips were caught, there was significant variation in

Tables 6.1a & b Total numbers of *S. aurantii* recorded on Dispersal / Emergence traps in relation to orientation around, and distance from, the citrus tree trunk: a) Week 1 & b) Week 2.

a) Week 1

Larvae

	Tree 1				Tree 2				Tree 3				
	Orientation				Orientation				Orientation				
Distance (cm)	N	E	S	W	N	E	S	W	N	E	S	W	Total
30	1	0	0	0	1	0	0	0	1	0	0	0	3
60	0	0	0	0	0	0	0	0	0	0	1	0	1
90	1	0	0	0	1	0	0	0	0	0	0	0	2
120	0	0	0	0	0	0	0	1	0	0	1	0	2
Total	2	0	0	0	2	0	0	1	1	0	2	0	8

Adults

	Orientation				Orientation				Orientation				
Distance (cm)	N	E	S	W	N	E	S	W	N	E	S	W	Total
30	1	1	0	0	1	1	0	0	1	1	1	0	7
60	0	1	0	0	0	1	0	0	0	0	1	1	4
90	0	0	0	0	0	0	0	0	0	0	1	0	1
120	0	1	0	0	0	1	0	0	0	1	0	0	3
Total	1	3	0	0	1	3	0	0	1	2	3	1	15

b) Week 2

Larvae

	Tree 1				Tree 2				Tree 3				
	Orientation				Orientation				Orientation				
Distance (cm)	N	E	S	W	N	E	S	W	N	E	S	W	Total
30	0	1	0	0	3	5	7	8	13	2	5	13	57
60	0	0	0	0	0	4	4	4	8	1	0	10	31
90	0	2	0	0	4	4	4	2	4	1	4	4	29
120	0	0	0	0	0	2	2	1	3	2	0	4	14
Total	0	3	0	0	7	15	17	15	28	6	9	31	131

Adults

	Orientation				Orientation				Orientation				
Distance (cm)	N	E	S	W	N	E	S	W	N	E	S	W	Total
30	1	5	1	3	1	2	3	1	3	2	1	1	24
60	2	0	1	0	0	2	3	2	4	4	3	2	23
90	0	1	1	0	0	1	9	2	3	0	5	1	23
120	0	0	0	0	1	1	2	0	3	0	7	2	16
Total	3	6	3	3	2	6	17	5	13	6	16	6	86

Table 6.1c Total numbers of *S. aurantii* recorded on Dispersal / Emergence traps in relation to orientation around, and distance from, the citrus tree trunk: Week 3.

c) Week 3

Larvae

	Tree 1				Tree 2				Tree 3				
	Orientation				Orientation				Orientation				
Distance (cm)	N	E	S	W	N	E	S	W	N	E	S	W	Total
30	0	1	0	0	8	13	8	6	15	12	10	11	84
60	2	0	0	0	11	5	9	6	10	15	13	10	81
90	1	0	3	0	6	2	17	6	8	20	7	5	75
120	9	0	2	1	5	8	10	13	6	26	7	5	92
Total	12	1	5	1	30	28	44	31	39	73	37	31	332

Adults

	Orientation				Orientation				Orientation				
Distance (cm)	N	E	S	W	N	E	S	W	N	E	S	W	Total
30	0	0	0	0	1	1	0	0	2	12	0	0	16
60	6	0	0	0	1	0	0	1	1	3	0	3	15
90	3	0	0	2	1	0	0	2	1	1	0	1	11
120	0	0	0	0	2	0	0	0	1	3	0	0	6
Total	9	0	0	2	5	1	0	3	5	19	0	4	48

Table 6.2 Analysis (using Mann Whitney paired test) of the total numbers of *S. aurantii* caught on Dispersal/Emergence traps at each of 16 trap positions combining orientation and distance from the citrus tree trunk. Raw data presented in table 6.1.

a) Comparison of thrips trapped per tree in different weeks.

Tree 1	Z	P (two-tailed)	
Week 1 vs. Week 2	1.44	0.15	N.S.
Week 1 vs. Week 3	1.64	0.10	N.S.
Week 2 vs. Week 3	0.38	0.70	N.S.
Tree 2			
Week 1 vs. Week 2	4.24	<0.001	***
Week 1 vs. Week 3	4.87	<0.001	***
Week 2 vs. Week 3	2.73	<0.001	***
Tree 3			
Week 1 vs. Week 2	2.73	<0.001	***
Week 1 vs. Week 3	4.64	<0.001	***
Week 2 vs. Week 3	4.86	<0.001	***

b) Comparison of thrips trapped per week under different trees.

Week 1	Z	P (two-tailed)	
Tree 1 vs. Tree 2	0.11	0.91	N.S.
Tree 1 vs. Tree 3	1.24	0.22	N.S.
Tree 2 vs. Tree 3	0.75	0.46	N.S.
Week 2			
Tree 1 vs. Tree 2	3.26	<0.001	***
Tree 1 vs. Tree 3	3.23	<0.001	***
Tree 2 vs. Tree 3	1.27	0.21	N.S.
Week 3			
Tree 1 vs. Tree 2	3.41	<0.001	***
Tree 1 vs. Tree 3	3.44	<0.001	***
Tree 2 vs. Tree 3	1.68	0.09	N.S.

the thrips numbers recorded between trees in the same week. There were also differences on the same tree in different weeks. Combination of the data across trees, and across sampling weeks is therefore problematic.

The effect of trap orientation was investigated by combining the trap counts at different distances from the trunk (table 6.3). No clear picture emerged, with four of the comparisons significant and five showing no significance. In the four replicates with significant differences, most thrips were trapped in the north, south, north and east respectively. Given this variation, it is not surprising that the combined totals of the nine replicates gave no indication of a significant directional bias.

The effects of trap distance from the trunk were similarly analyzed by combining results in the four different quadrants (table 6.4). Only three of the individual comparisons indicated significant differences in the numbers trapped at different distances. In each case the largest numbers were collected at 30cm, the nearest traps to the trunk. A combination of the nine replicates similarly indicated a significant trend for the numbers of thrips caught to diminish the further away from the trunk the trap was placed (table 6.4).

In view of these results it was decided for the long-term monitoring experiment to place the four traps at each cardinal compass quadrant, 30cm from the trunk.

Table 6.3 The effects of trap orientation on the numbers of *S. aurantii* recorded on Dispersal/Emergence traps under citrus trees. The data for each orientation is pooled from traps at four distances. X^2 tests are against an expected 1:1:1:1 ratio.

			Orientation						
			N	E	S	W	X^2	P	
Tree 1	Week 1	Observed	3	3	0	0	3.00	0.08	N.S.
		Expected	1.5	1.5	1.5	1.5			
	Week 2	Observed	3	9	3	3	6.00	0.11	N.S.
		Expected	4.5	4.5	4.5	4.5			
	Week 3	Observed	21	1	5	3	33.47	<0.001	***
		Expected	7.5	7.5	7.5	7.5			
Tree 2	Week 1	Observed	3	3	0	1	2.11	0.34	N.S.
		Expected	1.75	1.75	1.75	1.75			
	Week 2	Observed	9	21	34	20	14.95	<0.001	***
		Expected	21	21	21	21			
	Week 3	Observed	35	29	44	34	3.30	0.35	N.S.
		Expected	35.5	35.5	35.5	35.5			
Tree 3	Week 1	Observed	2	2	5	1	3.60	0.31	N.S.
		Expected	2.5	2.5	2.5	2.5			
	Week 2	Observed	41	12	25	37	17.80	<0.001	***
		Expected	28.8	28.8	28.8	28.8			
	Week 3	Observed	44	92	37	35	41.88	<0.001	***
		Expected	52	52	52	52			
Total of nine replicates		Observed	161	172	153	134	4.97	0.17	N.S.
		Expected	155	155	155	155			

Table 6.4 Analysis (using X^2 Goodness-of-fit) of pooled numbers of *S. aurantii* recorded on Dispersal/Emergence traps under citrus trees in relation to distance from the trunk.

			Distance (cm)				X^2	P	
			30	60	90	120			
Tree 1	Week 1	Observed	3	1	1	1	2.00	0.57	N.S.
		Expected	1.5	1.5	1.5	1.5			
	Week 2	Observed	11	3	4	0	12.67	<0.001	***
		Expected	4.5	4.5	4.5	4.5			
	Week 3	Observed	1	8	9	12	8.67	0.03	N.S.
		Expected	7.5	7.5	7.5	7.5			
Tree 2	Week 1	Observed	3	1	1	2	1.57	0.67	N.S.
		Expected	1.75	1.75	1.75	1.75			
	Week 2	Observed	30	19	26	9	12.10	<0.001	***
		Expected	21	21	21	21			
	Week 3	Observed	37	33	34	38	0.48	0.92	N.S.
		Expected	35.5	35.5	35.5	35.5			
Tree 3	Week 1	Observed	4	3	1	2	2.00	0.57	N.S.
		Expected	2.5	2.5	2.5	2.5			
	Week 2	Observed	40	32	22	21	8.44	0.04	*
		Expected	28.8	28.8	28.8	28.8			
	Week 3	Observed	62	55	43	48	13.96	0.27	N.S.
		Expected	52	52	52	52			
Total of nine replicates		Observed	191	155	141	133	12.75	<0.001	***
		Expected	155	155	155	155			

Population monitoring

For convenience, the results for the long-term monitoring experiment have been divided into three parts; September 1986 to May 1987, June 1987 to January 1988 and June 1988 to December 1988.

a) September 1986 to May 1987

Thrips abundance

From September 1986 to May 1987 a total of 2587 larval and 1154 adult *S. aurantii*, 11 adult *T. tenellus*, 195 *Haplothrips* spp. larvae and 53 adults (mainly *H. bedfordi*), and 19 adults of other species were caught on the D/E traps (table 6.5a). 10 of the 11 flower-feeding (Anon 1985b) *T. tenellus* were caught during September, the month when full-blossom and subsequent petal-fall occurs. Although the larvae of *S. aurantii* and *T. tenellus* could not always be told apart with absolute certainty (see above section on identification of larvae), the rarity of adults of the latter suggests that the consequences of any confusion would be minimal in a pest monitoring situation. *Haplothrips* spp., one of which is known as a predator of *S. aurantii* (Jacot-Guillarmod 1941), were almost absent during the months of September, October and November. It was only from December onwards that appreciable numbers began to be caught, most larvae being caught in January and most adults in February. Numbers then declined significantly from March onwards. As evident from table 6.5a, numbers of *Haplothrips* spp. were very low in comparison to *S. aurantii*.

Table 6.5 Monthly summaries of thrips caught on 24 Dispersal/Emergence traps under six citrus trees. Larval figures for *S. aurantii* include a small proportion of other thrips larvae (see text).

a) September 1986 - May 1987

		Month								
		S	O	N	D	J	F	M	A	M	TOTAL
S. aurantii	larvae	349	346	427	673	182	111	106	328	65	2587
	adults	81	212	148	413	73	80	44	86	17	1154
T. tenellus	adults	10	1	0	0	0	0	0	0	0	11
Haplothrips	larvae	0	0	2	46	67	51	16	10	3	195
	adults	1	0	0	4	7	34	4	2	1	53
Other adults		7	0	0	4	0	2	3	1	2	19

b) June 1987 - January 1988

		Month								
		J	J	A	S	O	N	D	J	TOTAL
S. aurantii	larvae	7	7	13	237	171	133	33	424	1025
	adults	6	1	5	72	118	77	42	176	497
T. tenellus	adults	0	0	0	10	5	27	0	0	42
Haplothrips	larvae	5	0	3	6	7	4	8	42	75
	adults	0	1	0	0	1	2	2	11	17
Other adults		0	2	0	3	8	3	2	1	19

c) June 1988 - December 1988

		Month							
		J	J	A	S	O	N	D	TOTAL
S. aurantii	larvae	2	0	21	408	41	201	145	818
	adults	2	2	2	111	64	25	77	283
T. tenellus	adults	0	0	0	18	0	0	1	19
Haplothrips	larvae	0	0	0	2	0	4	6	12
	adults	0	0	1	1	7	0	0	9
Other adults		2	0	2	1	0	2	2	9

Population fluctuations of *S. aurantii*

During the most economically critical months of September to December, four peaks of *S. aurantii* larvae dropping to the ground and adults emerging were recorded (figures 6.1 & 6.2). The first peak occurred at petal-fall during the latter half of September as the first flush of the growing season was hardening off. The second peak in late October was at a time when the trees were not flushing, the larvae must therefore have fed upon young fruit before dropping to the ground to pupate. The second flush of the season began in early November and lasted until early December. The third peak of thrips was recorded in the middle of this flush and the fourth at the end of the flush period. Numbers of both adults and larvae declined from late December and remained relatively low throughout January to March. At the end of the autumn flush in April a further peak of larvae and adults was recorded before numbers declined to a minimum in May.

Sex ratios of *S. aurantii* adults

Of the 1154 emerging adult *S. aurantii* caught on the underside of the D/E traps during this period, 416 (36.0%) were males and 738 (64.0%) were females. Table 6.6a shows that in every month males made up less than 50% of the emerging population, and in 7 out of the 9 months there was a significant excess of females. This was also the case for the combined totals.

During the early part of the period, from September to January, mean monthly male percentages ranged from 45.3% in November to 35.4% in December (table 6.6a). The male percentage was even lower from February to May, ranging from 29.5% in March to only 17.6% in May. The decline in the proportion of males emerging was

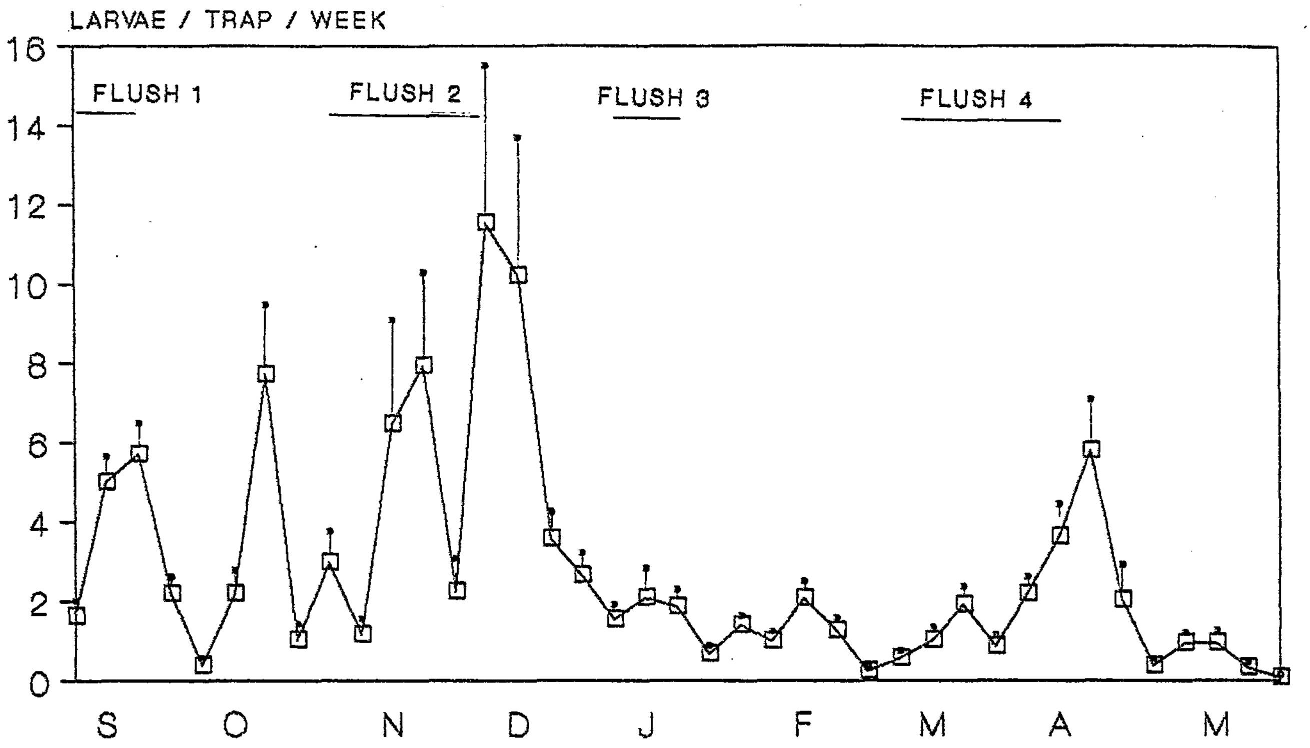


Figure 6.1. Mean (+ standard error of) weekly numbers of *S. aurantii* larvae caught on the top surface of Dispersal / Emergence traps, and the timing of flush periods on the citrus trees, September 1986 - May 1987.

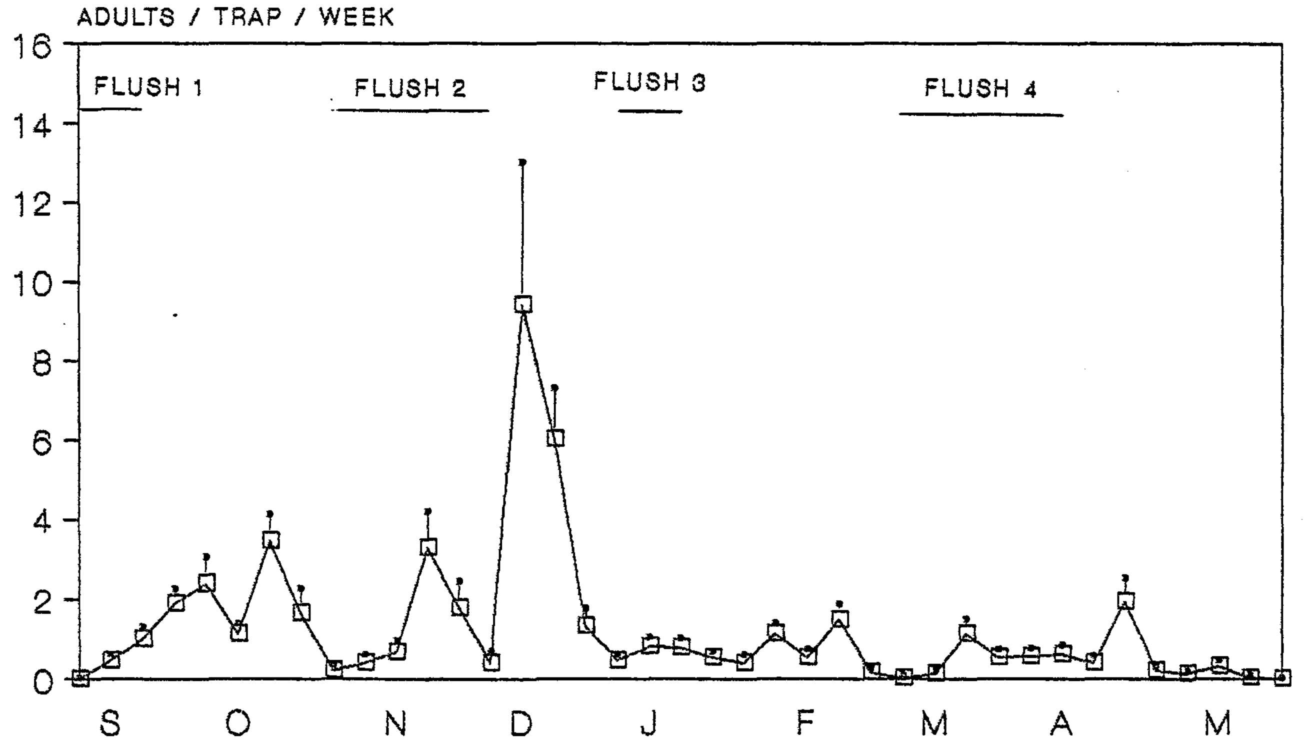


Figure 6.2. Mean (+ standard error of) weekly numbers of *S. aurantii* adults caught on the bottom surface of Dispersal / Emergence traps, and the timing of flush periods on the citrus trees, September 1986 - May 1987.

Table 6.6. Monthly summaries of citrus thrips caught on 24 Dispersal/Emergence traps under six citrus trees. X^2 values refer to a comparison of the proportion of males and females with a 1:1 ratio. Larval figures for S. aurantii include a small proportion of other thrips larvae (see text). The emergence rate is the number of adults emerging divided by the number of larvae dropping to the ground.

a) September 1986 - May 1987

					Month					
	S	O	N	D	J	F	M	A	M	TOTAL
S. aurantii										
Larvae	349	346	427	673	182	111	106	328	65	2587
Adults	81	212	148	413	73	80	44	86	17	1154
Males	36	80	67	146	27	22	13	22	3	416
Females	45	132	81	267	46	58	31	64	14	738
% males	44.4	37.7	45.3	35.4	37.0	27.5	29.5	25.6	17.6	36.0
% females	55.6	62.3	54.7	64.6	63.0	72.5	70.5	74.4	82.4	64.0
X^2	1.00	12.75	1.32	35.45	4.95	16.20	7.36	20.51	7.11	89.85
P	0.32	<0.001	0.25	<0.001	0.03	<0.001	<0.001	<0.001	<0.001	<0.001
	N.S.	***	N.S.	***	*	***	***	***	***	***
Emergence rate (%)	23.2	61.3	34.7	61.4	40.1	72.1	41.5	26.2	26.2	44.6

b) June 1987 - January 1988

				Month					
	J	J	A	S	O	N	D	J	TOTAL
S. aurantii									
Larvae	7	7	13	237	171	133	33	424	1025
Adults	6	1	5	72	118	77	42	176	497
Males	2	0	2	22	42	33	14	60	175
Females	4	1	3	50	76	44	28	116	322
% males	33.3	0.0	40.0	30.6	35.6	42.9	33.3	34.1	35.2
% females	66.7	100.0	60.0	69.4	64.4	57.1	66.7	65.9	64.8
X^2	0.67	-	0.20	10.50	9.80	1.57	4.67	17.82	142.88
P	0.40	-	0.65	<0.001	<0.001	0.21	0.03	<0.001	<0.001
	N.S.	N.S.	N.S.	***	***	N.S.	*	***	***
Emergence rate (%)	85.7	14.3	38.5	30.4	69.0	57.9	127.3	41.5	48.5

c) June 1988 - December 1988

				Month				
	J	J	A	S	O	N	D	TOTAL
S. aurantii								
Larvae	2	0	21	408	41	201	145	818
Adults	2	2	2	111	64	25	77	283
Males	1	0	1	32	30	10	26	100
Females	1	2	1	79	34	15	51	183
% males	50.0	0.0	50.0	28.8	46.9	40.0	33.8	35.3
% females	50.0	100.0	50.0	71.2	53.1	60.0	66.2	64.7
X^2	0.00	-	0.00	19.90	0.25	1.00	8.11	24.34
P	0.00	-	0.00	<0.001	0.62	0.32	<0.001	<0.001
	N.S.	N.S.	N.S.	***	N.S.	N.S.	***	***
Emergence rate (%)	100.0	-	9.5	27.2	156.1	12.4	53.1	34.6

Mann - Whitney paired test on the months with >10 thrips emerging showed that more females than males were emerging from the soil, n = 19, Z = 6.07, P (two-tailed) < 0.001.

significant in this sampling period (figure 6.3). Numbers of thrips emerging in May were insufficient to allow inclusion in the statistical analysis.

Table 6.7 examines the proportion of emerging male and female *S. aurantii* in relation to the flushing rythmn of the trees, a similar analysis to that described in the previous chapter dealing with sticky yellow traps. Four flush periods were detected from September until the beginning of June 1987 (Table 6.7a). At no time did the proportion of males emerging during a flush or between flushes exceed 50%, the highest percentage being 44.79 during the second flush period, and the lowest being 20.27 after the fourth flush had hardened off. During flushes, the male percentage tended to be slightly higher than during adjacent between-flush periods, but of the seven statistical comparisons made between adjacent time periods only one showed marginal significance. The totals for the four flush and inter-flush periods did nonetheless indicate a tendency for the proportion of males to be higher during flush periods (P = 0.04).

Emergence rates

During the 9 month period, 2587 *S. aurantii* larvae were trapped dropping to the ground and 1154 adults were trapped after emergence from the soil , giving a mean emergence rate of 44.6% (table 6.6a). In other words, the estimated mortality of larvae in the soil was 55.4%. Emergence rates varied from a high of 72.1% in February to a low of 23.2% in September, but no obvious seasonal trends in larval success were present.

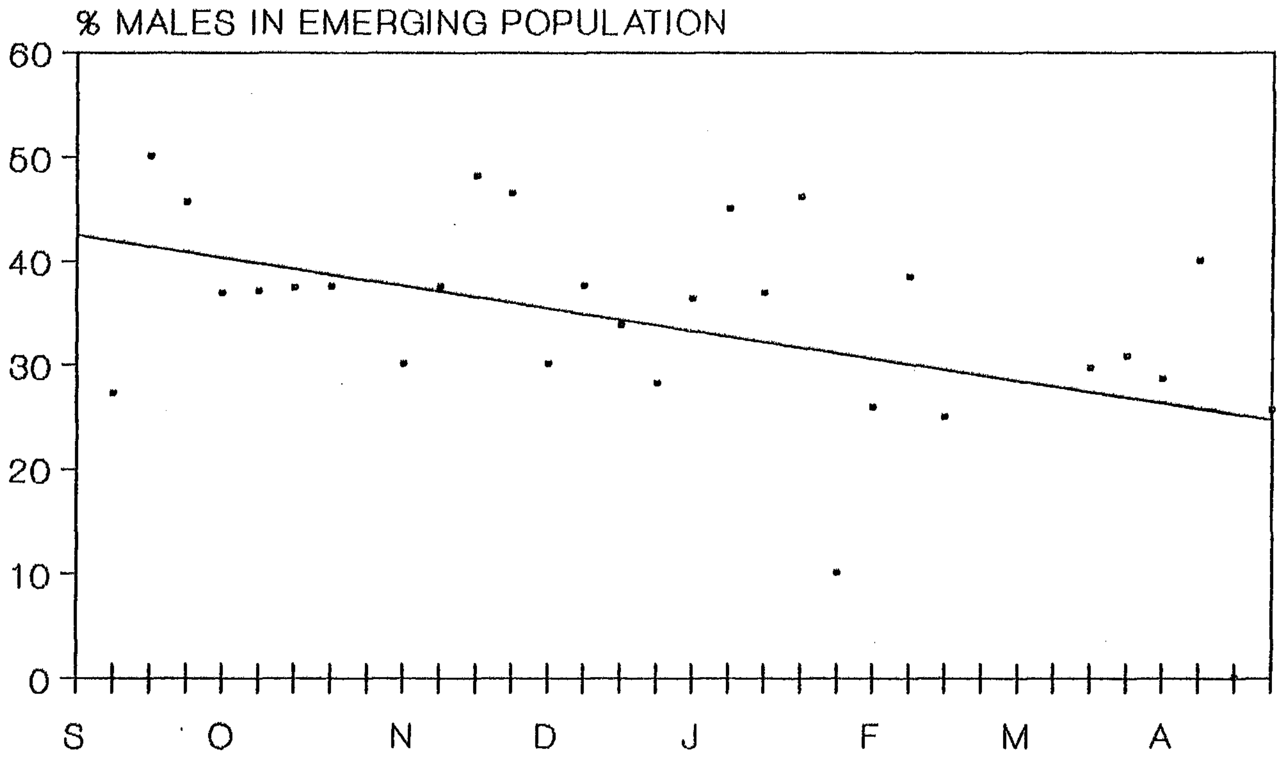


Figure 6.3. Weekly percentage of adult male *S. aurantii* caught on Dispersal/Emergence traps, September 1986 - April 1987. $R^2 = 22.86\%$, $y = -0.53x + 42.54$, $P < 0.01$.

Table 6.7 The proportion of male and female adult *S. aurantii* caught on D/E traps after emergence from the leaf litter in relation to flushing and non-flushing of citrus, 8th September 1986 - 26th December 1988. N.B. Flush #1 is the flush on which the flowers are borne, i.e. the "spring" flush. Subsequent flushes throughout the growing (not calendar) year are numbered #2, #3 etc. X^2 values refer to comparisons of the proportion of males and females recorded during adjacent time periods.

		S. aurantii		Ratio	%		
Time Period	Flush	Males	Females	M:F	Males	X^2	P
a) *Sept '86 - May '87*							
08/09/86 - 22/09/86	#1	15	20	0.75	42.86	0.22	0.64
29/09/86 - 27/10/86	-	98	155	0.63	38.74	1.50	0.22
03/11/86 - 08/12/86	#2	73	90	0.81	44.79	4.25	0.04 *
15/12/86 - 29/12/86	-	143	260	0.55	35.48	0.39	0.53
05/01/87 - 19/01/87	#3	20	30	0.67	40.00	2.17	0.14
26/01/87 - 02/03/87	-	29	74	0.39	28.16	0.23	0.63
09/03/87 - 13/4/87	#4	23	50	0.46	31.51	2.42	0.12
20/04/87 - 01/06/87	-	15	59	0.25	20.27		
Totals	Flush	131	190	0.69	40.81	4.37	0.04 *
	No Flush	285	548	0.52	34.21		
b) *June '87 - Feb '88*							
08/06/87 - 27/07/87	-	2	5	0.40	28.57	0.13	0.71
03/08/87 - 21/09/87	#1	9	16	0.56	36.00	0.00	0.98
28/09/87 - 21/12/87	-	103	181	0.57	36.27	1.92	0.17
28/12/87 - 25/01/88	#2	28	70	0.40	28.57	2.52	0.11
01/02/88	-	33	50	0.66	38.82		
Totals	Flush	37	86	0.43	30.08	1.89	0.17
	No Flush	138	236	0.58	36.90		
c) *June - December '88*							
13/06/88 - 01/08/88	-	1	3	0.33	25.00	0.44	0.51
08/08/88 - 19/09/88	#1	4	5	0.80	44.44	0.32	0.57
26/09/88 - 31/10/88	-	59	109	0.54	35.12	0.10	0.75
07/11/88 - 05/12/88	#2	13	27	0.56	32.50	0.22	0.64
12/12/88 - 26/12/88	-	23	39	0.59	37.10		
Totals	Flush	17	32	0.53	34.69	0.01	0.92
	No Flush	83	151	0.55	35.47		
d) During 24 months of experiment.	Flush	185	308	0.60	37.53	0.93	0.33
	No Flush	506	935	0.54	35.11		

b) June 1987 to January 1988

Thrips Abundance

Over the 8-month sampling period a total of 1025 larval and 497 adult *S. aurantii* were caught, as well as 42 adult *T. tenellus*, 75 larval and 17 adult *Haplothrips* spp., and 19 adults of other thrips species (table 6.5b).

A few blossoms persisted in the orchard during the latter half of October and probably accounted for the comparatively late trapping of some adults of *T. tenellus* in November. This was in contrast to the previous year when this species was practically absent after September. With *Haplothrips* spp., the pattern of 1986 was repeated in that numbers were very low during the most critical months for citrus thrips damage. Numbers only started to increase significantly in January.

Population fluctuations of *S. aurantii*

Only 14 *S. aurantii* larvae and seven adults were trapped during June and July (table 6.5b). During these two months the trees were dormant and clearly there was very little movement of thrips to and from the soil, indicating a low overwintering population (figures 6.4 and 6.5).

The onset of the first flush of the growing season in early August produced little change in this picture of low thrips activity. However, from the middle of September, when the first flush was beginning to harden off and blossoming was nearly over, the number of larvae dropping to the ground increased markedly with a peak at the end of this month. Similarly, adult emergence showed a peak at this time.

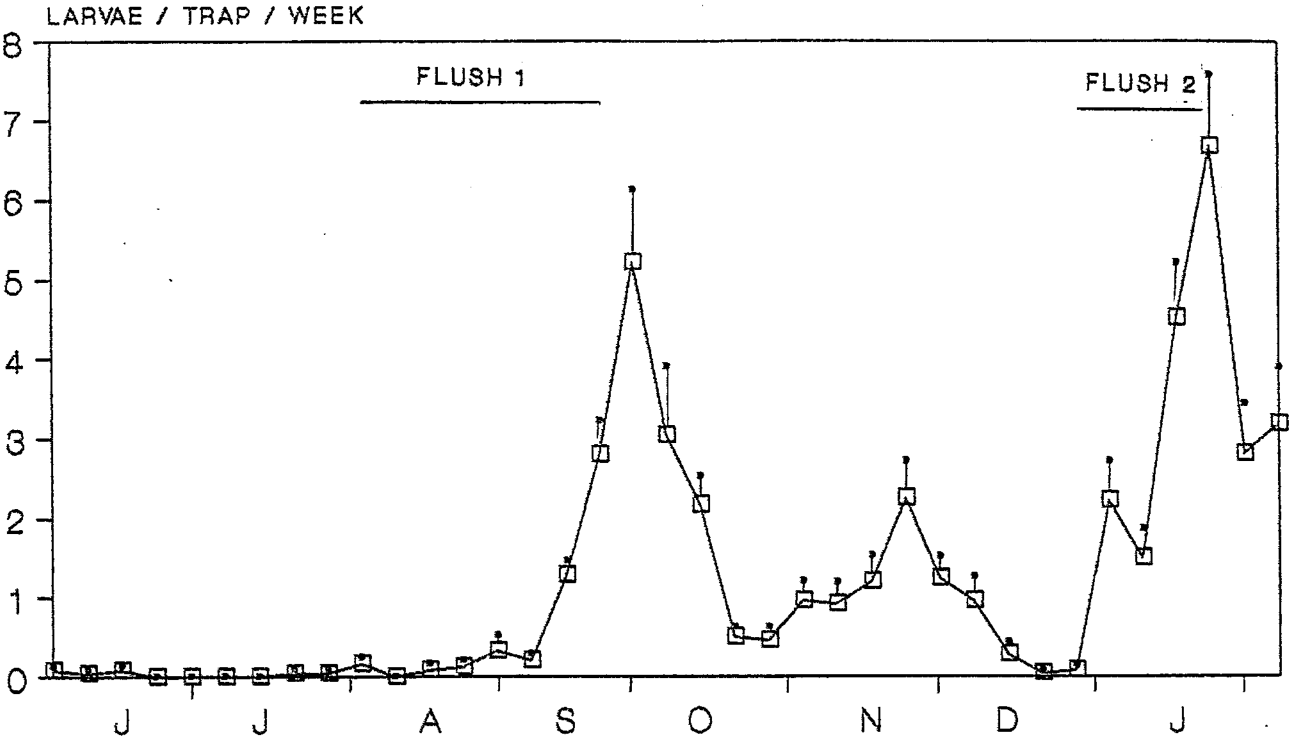


Figure 6.4. Mean (+ standard error of) weekly numbers of *S. aurantii* larvae caught on the top surface of Dispersal / Emergence traps, and the timing of flush periods on the citrus trees, June 1987 - January 1988.

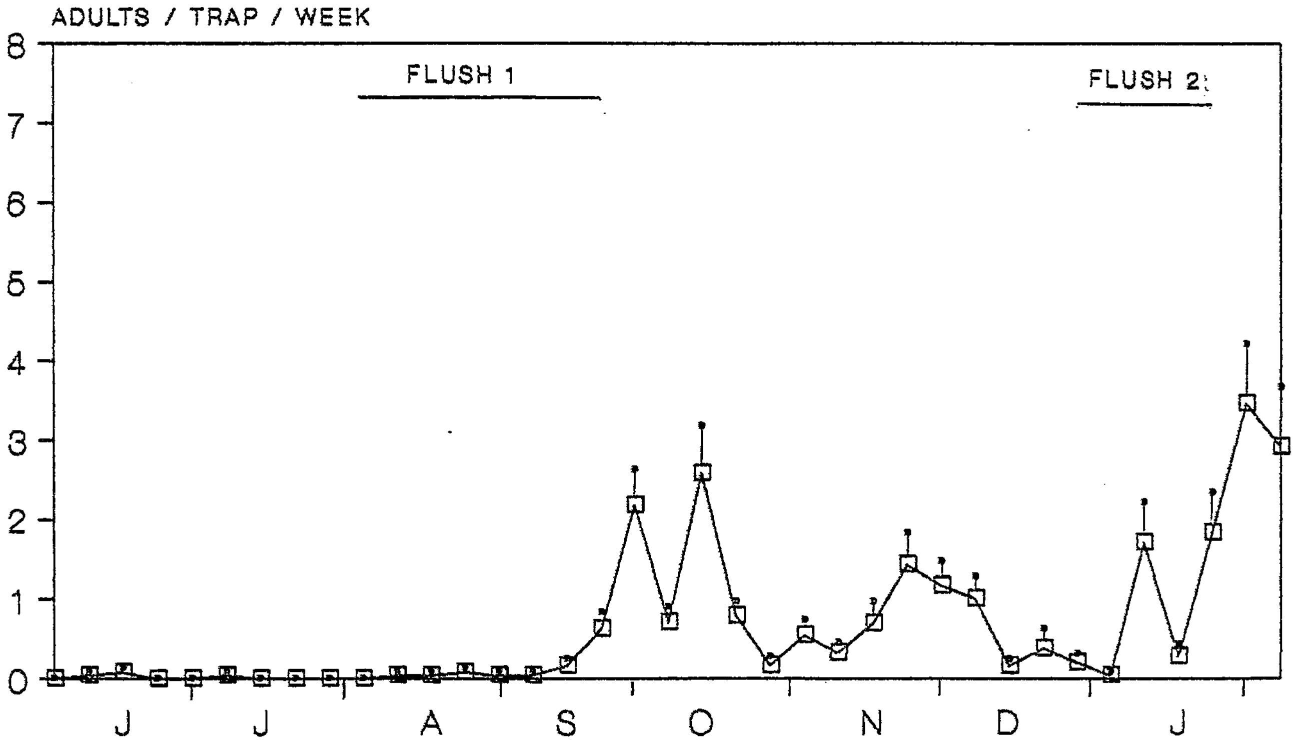


Figure 6.5. Mean (+ standard error of) weekly numbers of *S. aurantii* adults caught on the bottom surface of Dispersal / Emergence traps, and the timing of flush periods on the citrus trees, June 1987 - January 1988.

The second peak of adults and larvae was recorded during late November. As in the previous growing season, the trees had no new vegetative growth at this time and so young fruitlets rather than new flush were supporting this particular generation of thrips larvae during their development.

A second flush appeared in the latter half of December and lasted until the middle of January, and large peaks of larvae and adults were recorded as these leaves were hardening off.

Sex ratios of *S. aurantii* adults

From June 1987 until the beginning of February 1988, the proportion of *S. aurantii* emerging was 35.2% males and 64.8% females, a significant excess of the latter over a 50:50 sex ratio (table 6.6b), and very similar to that recorded during September 1986 to May 1987. In all months, as in the previous survey period, males made up less than 50% of the population, means ranging from 0% in July 1987, when a single female was trapped, to 42.9% in November 1987. In the three winter months of June, July and August, numbers of adults emerging were insufficient to allow meaningful statistical analysis. However from September to January, when numbers were much higher, four of these months showed a significantly larger proportion of females emerging than males (table 6.6b). There was no evidence of a higher proportion of males emerging during flush periods, as none of the sex ratio comparisons between adjacent time periods or between totals were significant (table 6.7b).

Emergence rates

1025 *S. aurantii* larvae were trapped dropping to the ground and 497 adults were trapped after emergence, giving a mean emergence rate of 48.5% (table 6.6b). This was very similar to the rate observed in the previous section. The estimated emergence rate nonetheless varied considerably, from as high as 127.3% in December to 14.3% in July. The former estimate of greater than 100% is an artifact resulting from short-term changes in the rates of larvae falling to the ground.

c) June 1988 - December 1988.

Thrips Abundance

During this sampling period, a total of 818 larval and 283 adult *S. aurantii*, 19 adult *T. tenellus*, 12 larval and 9 adult *Haplothrips* spp., and 9 adults of other species were recorded (table 6.5c).

Population fluctuations of *S. aurantii*

As in 1987, a very low overwintering population of citrus thrips was evident in 1988 (figures 6.6 and 6.7), and throughout June and July a total of only 2 larvae and 4 adults were recorded (table 6.5c). The first peak in larval numbers occurred at the end of the third week of September, at the end of blossoming and as the flush hardened off. A corresponding peak of adult emergence was recorded the following week at the end of September. The numbers of larvae declined during late September and October. During November larvae increased in number, peaking at the end of this month as the second flush of the growing

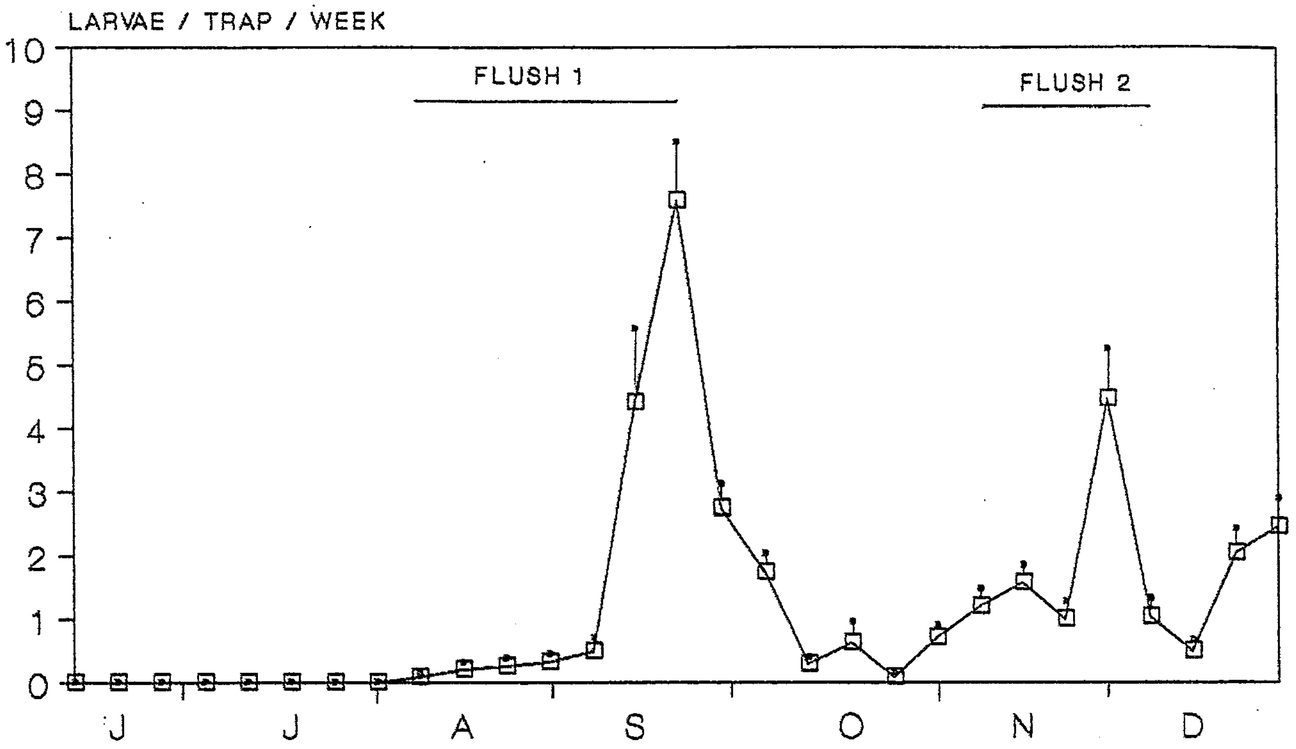


Figure 6.6. Mean (+ standard error of) weekly numbers of *S. aurantii* larvae caught on the top surface of Dispersal / Emergence traps, and the timing of flush periods on the citrus trees, June - December 1988.

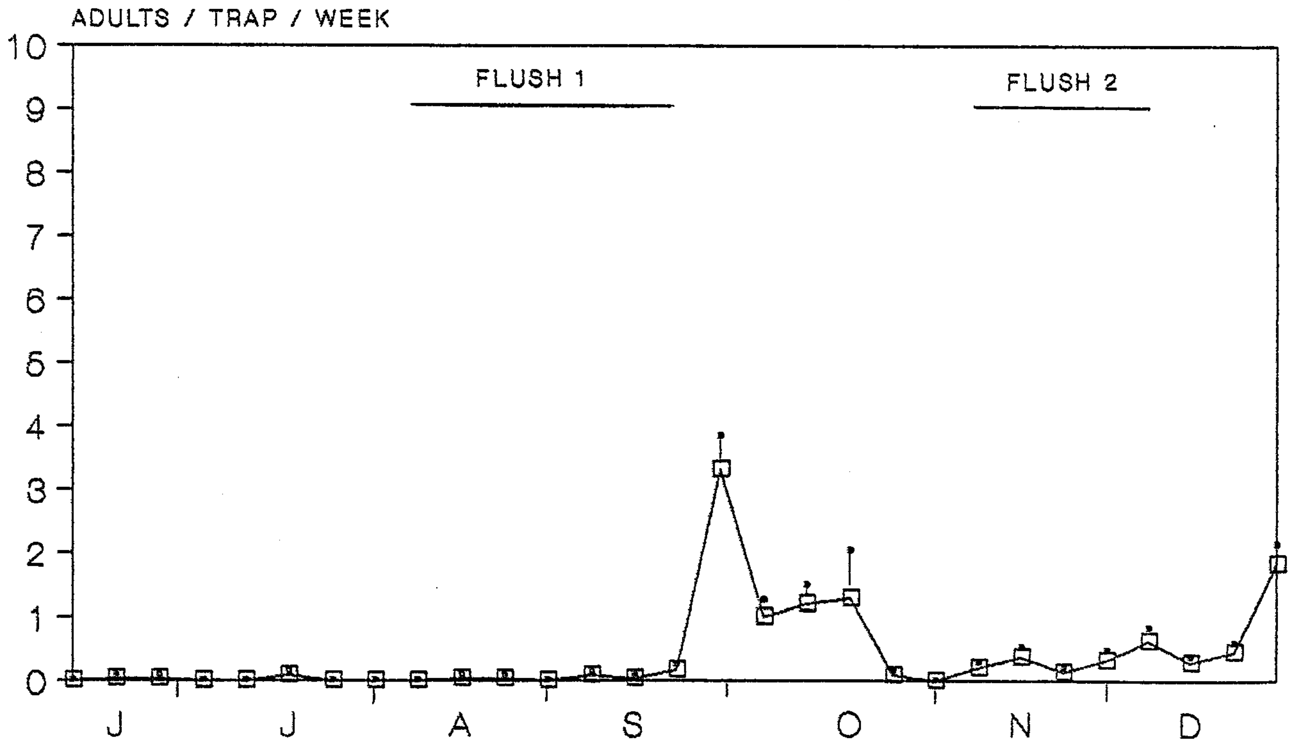


Figure 6.7. Mean (+ standard error of) weekly numbers of *S. aurantii* adults caught on the bottom surface of Dispersal / Emergence traps, and the timing of flush periods on the citrus trees, June - December 1988.

season was hardening off. There was no clear peak of adults at this time, possibly due to high mortality of larvae in the soil (see discussion).

Sex ratio of *S. aurantii* adults

From June to December 1988, 35.3% of the trapped thrips were males and 64.7% females (table 6.6c), very similar to the results obtained in the two previous sampling periods. The monthly mean sex ratios ranged from 0% males in July, when only 2 females were caught, to 50% males in June and August when only one of each sex was caught.

Two flushes were detected during this seven month period (figures 6.6 and 6.7). The highest proportion of males (44.44%) was recorded during flush 1, although it should be noted that a total of only nine adults were recorded at that time. Analysis of the proportions of males and females emerging in adjacent flush and between-flush periods revealed no significant trend (table 6.7c).

Emergence rates

A total of 818 *S. aurantii* larvae were caught dropping to the ground and 283 adults were caught after emergence, giving a mean emergence rate of 34.6%, somewhat lower than the rate in the two previous sampling periods. The rate was highest in July, when only two adults were caught, and no larvae, and lowest in August at 9.5%.

SUMMARY OF RESULTS

The initial experiments revealed a tendency for greater numbers of thrips to be caught close to the tree trunk: 30.81% of the total was recorded on traps placed 30cm from the tree trunk. The number of thrips declined progressively with increasing distance from the trunk, with 21.45% of the thrips recorded at 120cm. In contrast trap orientation around the trunk did not have significant effects on trapping rates. During the population monitoring phase of the study, a total of 4712 mature second-instar larvae were caught as they dispersed to ground to pupate. 4430 (94.02%) were larvae of *S. aurantii* (apart from a very small proportion of other species, see section above on identification of larvae) and 282 (5.98%) were larvae of *Haplothrips* spp. 2132 adult thrips were caught after emergence, of which 1934 (90.71%) were *S. aurantii*, 72 (3.38%) *T. tenellus*, 79 (3.71%) *Haplothrips* spp., and 47 (2.20%) of all other species. Overall, 35.73% of *S. aurantii* adults emerging were males and 64.27% were females, indicating an overall bias towards the latter. The highest monthly percentage of males recorded was 50%, but this was only in two months when the numbers of thrips emerging were extremely low. A trend was evident for the proportion of emerging males to decline from the beginning of spring (September) through to the end of autumn (May). Unfortunately, only one year's results were available, so the generality of this is uncertain (figure 6.3).

In all three years, the numbers of *S. aurantii* increased dramatically during late September, representing the pupation and emergence of the first generation of larvae and adults in the growing year, and coinciding with the hardening-off of the first flush of the season and the ending of the flowering period.

In the two years when a very low overwintering population was evident (1987 and 1988), the peak of second generation larvae descending to the ground occurred towards the end of November. Only in 1987 was the corresponding peak of emerging adults well-defined, while in 1988 numbers remained low. In 1986, when a high overwintering population was evident (from collections on yellow sticky traps, see chapter 5), three large peaks of thrips activity were recorded during the months of September to November. High numbers of thrips in winter would be more likely to exacerbate asynchrony of generations in spring, and it may be that the extra peak of thrips in October 1986 represents a second cohort.

Although there was variation between different time periods there was no overall tendency for the proportion of males emerging during flush periods to be higher than between them.

DISCUSSION

The D/E traps proved to be an effective monitoring device for citrus thrips, notwithstanding the minor problems experienced. In most cases, peaks of both life-stages were well-defined.

The identification of trapped adults was very easy, but the larvae scored as *S. aurantii* necessarily included a very small proportion of larvae of other species, mainly *T. tenellus*. The rarity of *T. tenellus*, the adults of which featured in very low numbers compared to *S. aurantii*, meant that this would not have serious consequences in a pest monitoring situation at Letaba. In California, even this minor problem does not arise because the most common species of thrips encountered on D/E traps (after *S. citri*) is the Western Flower Thrips *F. occidentalis* (Reed and Rich 1975), whose larvae and adults can be readily distinguished from *S. citri*.

Larvae and adults of *Haplothrips* spp. were readily distinguishable from the other genera. One member of the genus, *H. bedfordi* has previously been recorded as a citrus thrips predator (Jacot-Guillarmod 1941), but Bedford (1943) found that the species was only common on citrus thrips-infested fruit from January to April, after the most critical months for *S. aurantii* damage to fruit. The present study revealed a similar trend in that the population peaks were recorded somewhat late in the growing season and this, together with their low densities, explains why such predatory thrips have never been considered to be an effective biocontrol agent of *S. aurantii*.

The trapping results confirmed in a field situation the laboratory observations of Bedford (1943) that larvae of *S. aurantii* drop to the ground and pupate in the soil beneath citrus trees. A single pupa can nonetheless sometimes be discovered under the calyx of an orange but this appears to be extremely rare. Hall (1930) was therefore incorrect in saying that pupation took place only in the tree, as was Jeppson (1989) in his review who had clearly referred to Hall's work and not that of Bedford (1943).

The trend for catches of thrips to decline further away from the tree trunk was similar to the results of Reed & Rich (1975) with *S. citri*. They speculated that larvae moved inwards towards the darker centre of the tree before dropping to the ground. The same explanation could also apply to *S. aurantii*.

In the long-term monitoring study, the traps usually recorded clearly-defined peaks in the numbers of larvae and adults which were almost co-incident, as would be expected from the short pupation period in this species (Hall 1930). Peak emergence of adults thus usually occurred either in the same week or in the week following each peak of larvae dropping to the ground.

The trapping period covered two winters, those of 1987 and 1988. In both years there were no out-of-season fruit on the trees (chapter 5) and this potential food source was therefore unavailable during June and July. During these two months, very little thrips activity was recorded. In spring, the first peaks of larvae dropping to the soil and adults emerging occurred at the end of the first flush period (in the latter half of September), indicating that there was only time for one generation to develop on this particular food source. It also indicated how well synchronized the life-cycle of *S. aurantii* is to the phenology of citrus at this time of year, there being sufficient time for egg-laying by overwintering adults, hatching and full development of larvae before the flush hardened off.

In all three years, the first and economically-important peak of adult citrus thrips emerging during late September was always accompanied by or slightly preceded by large numbers of larvae dropping to the ground as the flush was hardening off. After 100% petal-fall, the first citrus thrips infestation on fruit was therefore not a result of mass emergence of adults from pupae which had remained dormant over winter. Such a pattern would have been typified by the trapping of adults first, and only after a number of weeks would larvae be trapped as the offspring of the original adults dispersed to ground. Initial infestation of fruit therefore takes place after a build-up of larval numbers on the new flush which appears in late July or early August. As the flush hardens off at the same time as flowering finishes, the whole population of newly-emerged adults is then concentrated on the very vulnerable small fruitlets. In the absence of control measures, this will occur very soon after petal-fall, with the resultant danger of severe economic damage very early in the growing season.

In 1987 and 1988, the second generation peak of thrips was recorded during late November, still well within the critical period for thrips damage. During 1986, a second peak was recorded somewhat earlier in the latter half of October possibly as a result of overlapping generations (different cohorts) following a winter in which comparatively large numbers of thrips overwintered on out-of season fruit (chapter 5). It is unlikely that this peak represents a true second generation because the third peak coincided closely with the occurrence of the second peak in the other two years (late November).

In California, Reed & Rich (1975) used the number of emerging adult *S. citri* relative to the number of larvae dropping to the ground as a measure of mortality during pupation. The greatest emergence rates they estimated (104% and 81%) were in a lemon orchard during two consecutive seasons. Mortalities were higher in orange orchards, where rates varied between 31% and 62%. In the present study trapping was carried out for 24 months, over which a mean emergence rate of 43.7% was recorded. The estimated mortality during pupation and emergence was therefore 56.3%. However, if one considers the biology of *S. aurantii* and the nature of the D/E trap, these figures may be underestimating the emergence rate. In the laboratory, Hall (1930) gave the combined length of the prepupal and pupal stages of *S. aurantii* as 3.92 days during October and November, while Bedford (1943) observed that increasing temperature shortened the development time and that during these moderately hot months the time taken for these life-stages varied between 4 and 7 days. Both in the present study and that of Reed & Rich (1975), D/E traps were examined in the field on a weekly basis. Bearing in mind the results of Hall (1930) and Bedford (1943), it is likely that in the field, particularly during the hotter months of the year, the length of time taken between a larva dropping to the ground and its emergence as an adult is less than seven days. Indeed the fact that the peaks of adults and larvae were so closely associated points to this (compare figures 6.1 and 6.2, figures 6.4 and 6.5, and 6.6 and 6.7). As the traps prevent larvae from reaching the ground, they effectively stop those adults which would have developed from larvae and would have emerged within the same week from being counted. The traps therefore can only record adults which developed from larvae which dropped the previous week. The mean emergence rate of 43.7% must therefore be viewed as an underestimate, in reality it may be much higher than this. Cycling of the traps at shorter intervals would overcome this problem, but then the workload of running such a monitoring system would necessarily be increased.

The trapping surfaces of the D/E trap are transparent, and do not actively attract thrips to them. Consequently, they give an absolute estimate of the thrips population. This is in contrast to coloured sticky traps, which vary in their attractiveness to different insect species as well as to the different sexes within the same species, and only supply a relative estimate of population density (Southwood 1978). The D/E trap is merely intercepting the larvae (on the top of the plate) and adults (on the bottom of the plate) in the course of their normal behaviour. Furthermore, any thrips emerging, whether male or female, would have an equal chance of being caught due to the enclosed nature of the underside of the trap, and an unbiased estimate of the adult emergence sex ratio is therefore obtained.

Over the 24 month trapping period, 35.73% of the emerging adults recorded were males and 64.27% were females. The adult population is therefore clearly female-biased, a very common phenomenon in Thysanoptera (Kendall & Capinera 1990). In this study, males, although in the minority, were not "very rare" as found by Hall (1930). On the other hand, they represented a higher proportion of the total population than was indicated by the field samples of 23.6% and 23% mentioned in Faure (1929) & Bedford (1943). The greater activity and willingness to fly of males observed by the latter author could however account for the less than representative catches of males in their samples, which were apparently collected by beating foliage over paper. The proportions of males and females recorded emerging in the present study must therefore represent a better estimate of the adult sex ratio than has been obtained previously.

Thrips generally have a haplodiploid sex-determination mechanism. It is thought that such haplodiploid animals normally possess the facultative ability (Hardy & Godfray 1990) to control the sex of the eggs that they lay (Nunney 1985, Fischer & Harper 1986). If the amount of effort expended in producing sons and daughters is equal and competition for mates occurs throughout the whole population then a 1:1 (equilibrium) sex ratio should result (Fisher 1958). However, a significant excess of females may result if local competition for mates and regular brother-sister mating occurs (Hamilton 1967) and, in species in which inbreeding is common, extreme female-bias may result (Herre 1985). This however presupposes that, among other conditions, a discrete batch of siblings develop gregariously from egg to adult. In the case of *S. aurantii*, although several larvae may develop together on a single fruit or shoot, they fall to the ground to pupate, and then must fly back to the tree after emergence. They should therefore undergo considerable dispersal from their siblings in the course of these journeys, even if all the larvae on a given fruit or shoot were brothers and sisters, (of which there is no guarantee). It therefore seems unlikely that in *S. aurantii* local mate competition is a significant factor, especially as copulation is observed regularly between adults on the tree canopy and thus fertilization of eggs presumably occurs after the adults have flown up into the foliage. An alternative explanation other than Local Mate Competition must therefore be sought for the female-biased sex ratios in this species.

The adult emergence sex ratio was less female-biased during spring, then increased progressively throughout the growing season until the end of autumn (figure 6.3). An explanation for this is not readily available, although as male thrips are haploid and arise from unfertilized eggs (Lewis 1973), it may be that at the end of winter there were a relatively large proportion of unmated females who were then forced to lay male eggs. The trend for the percentage of males among the emergees to be highest in spring and decrease throughout summer and autumn may therefore reflect a progressive decline in the proportion of unmated or "constrained" (Hardy & Godfray 1990) females.

7. A COMPARISON OF RESULTS FROM DISPERSAL/EMERGENCE TRAPS AND YELLOW STICKY TRAPS.

INTRODUCTION

In California, both Dispersal/Emergence and yellow sticky traps are used to monitor *S. citri*. As detailed in the above chapters, the latter type of trap is used extensively for monitoring *S. aurantii* in southern Africa, but the two trap types have never previously been used simultaneously in the same orchard so as to allow direct comparisons to be made between the results obtained.

METHODS

Counts of thrips obtained from September 1986 until the end of December 1988 from the six yellow sticky traps were compared with those from the 24 D/E traps placed under the same six citrus trees. The results were first compared on a calendar basis. Subsequently, thrips counts were analysed with respect to citrus tree phenology. Specific periods where comparisons were made were the phases of the flushing cycle as well as the economically critical period and thereafter.

The following points were borne in mind with respect to tree phenology and its interaction with *S. aurantii*. There are two food sources which *S. aurantii* can exploit on the citrus tree; young soft foliage and fruit, (flowers are not often visited). Young leaves are fed upon at any time of the year when they are available, whereas fruit become less and less palatable and therefore less vulnerable to attack as they increase in size (and presumably skin toughness) with the progression of the growing year. Opinions have varied as to the length of time that citrus fruit is vulnerable to damage. Earlier references (Hall 1930, Bedford 1943) quoted a relatively short danger period compared with later ones (Kamburov 1991). Many factors are involved, not least of which is the rate of fruit growth, which is largely dependent upon temperature and the water supply from irrigation and rainfall, as well as the type of cultivar which is attacked.

Experience over a number of years at Letaba Estates has shown that, after January, the main danger of thrips damage to navel fruit (the cultivar in the experimental orchard) has passed, although in exceptional years spraying for thrips may be necessary later than this. Fruit is obviously not present on the tree until petal-fall, at the end of the first flush and damage to them cannot therefore occur before this. However we have seen from the results in previous chapters that the first infestation on fruit occurs after large numbers of larvae have already descended to the ground after having fed on the first flush, and subsequently emerged as adults. For this reason, the catches of thrips during the first flush have been included in the "critical period". Therefore the critical period was considered to encompass the period between the beginning of the first flush and the end of January. The post-critical period was taken to be from the end of January until the beginning of the next "spring" flush (#1), during which time the fruit was considered to be more or less invulnerable to attack by *S. aurantii*, or had been harvested (after mid-April). A sequence of four phenological categories was thus erected: a) Critical period & Flush (C & F); b) Critical period & No Flush (C & NF); c) Post-Critical period & Flush (PC & F) and; d) Post-Critical period & No Flush (PC & NF).

RESULTS

Comparative sensitivity of the two trap types

During the sampling period, a total of 6634 citrus thrips were caught on the D/E traps of which 4430 were larvae and 1934 were adults (691 males and 1243 females). In the same period, 4469 adults (2643 males and 1826 females) were caught on the yellow traps (table 7.1).

Bearing in mind that for every one yellow trap there were four D/E traps under the same tree one can see that the former method is by far the more sensitive. Although the D/E trap samples two life-stages (mature second instar larvae as well as adults), while the yellow trap samples only adults, the mean number of citrus thrips caught (adults and larvae) per trap was only 0.37 that caught by each yellow trap.

Degree of correlation between the two trap types.

As only the D/E trap catches *S. aurantii* larvae no comparisons can be made with the yellow trap regarding this life-stage. When considering the monthly totals of adults recorded on each type of trap, a significant correlation was present ($R^2 = 59.37\%$, $P < 0.001$, figure 7.1). When considering catches of males alone, the correlation was improved ($R^2 = 70.41\%$, $P < 0.001$, figure 7.2). In contrast, the catches of females on the two trap types were not significantly correlated overall ($R^2 = 7.68\%$, $P = 0.19$, figure 7.3). If it is assumed that emergence traps provide an "absolute" estimate of thrips numbers, then the yellow traps were therefore a far more reliable indicator of the numbers of males in the

Table 7.1 Monthly summaries of *S. aurantii* adults recorded on 24 Dispersal/Emergence traps and 6 yellow sticky traps.

a) September 1986 - May 1987

		Month									
		S	O	N	D	J	F	M	A	M	Total
D/E Traps	Males	36	80	67	146	27	22	13	22	3	416
	Females	45	132	81	267	46	58	31	64	14	738
	% males	44.4	37.7	45.3	35.4	37.0	27.5	29.5	25.6	17.6	36.0
Yellow Traps	Males	202	245	177	374	242	54	33	109	28	1464
	Females	53	137	21	61	155	190	42	99	97	855
	% males	79.5	64.1	89.4	86.0	61.0	22.1	44.0	52.4	22.4	63.1

b) June 1987 - January 1988

		Month								
		J	J	A	S	O	N	D	J	Total
D/E Traps	Males	2	0	2	22	42	33	14	60	175
	Females	4	1	3	50	76	44	28	116	322
	% males	33.3	0.0	40.0	30.6	35.6	42.9	33.3	34.1	35.2
Yellow Traps	Males	10	8	29	114	205	107	69	79	621
	Females	55	36	7	63	130	71	97	124	583
	% males	15.4	18.2	80.6	64.4	61.2	60.1	41.6	38.9	51.6

c) June 1988 - December 1988

		Month							
		*J	J	A	S	O	N	**D	Total
D/E Traps	Males	1	0	1	32	30	10	26	100
	Females	1	2	1	79	34	15	51	183
	% males	50.0	0.0	50.0	28.8	46.9	40.0	33.8	35.3
Yellow Traps	Males	14	5	41	222	84	98	94	558
	Females	78	17	12	105	56	31	89	388
	% males	15.2	22.7	77.4	67.9	60.0	76.0	51.4	59.0

* from 13th June ** to 26th December

d) Combined totals during 24 months of experiment

	D/E traps	Yellow traps
Males	691	2643
Females	1243	1826
% Males	35.7	59.1

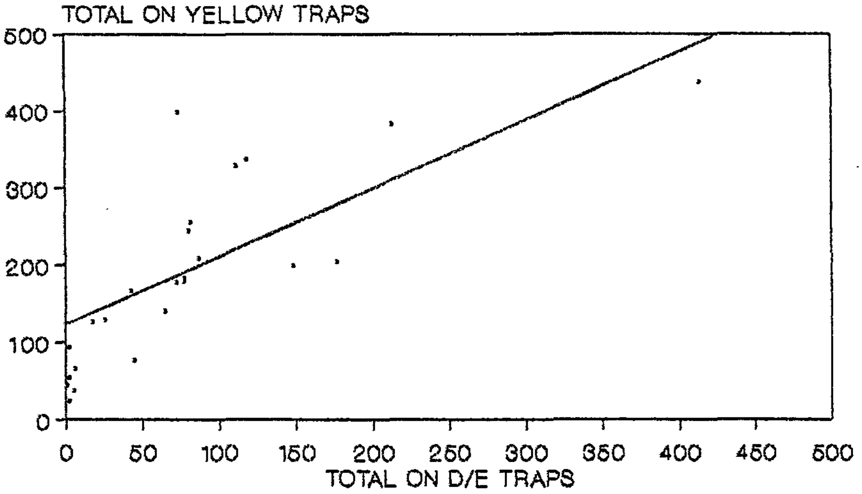


Figure 7.1. The relationship between the monthly total (male and female) numbers of *S. aurantii* adults recorded on a) 24 D/E traps after emerging and on b) 6 yellow traps. $R^2 = 59.4\%$, F-Ratio = 32.1, $y = 1.0x + 108.4$, $P < 0.001$.

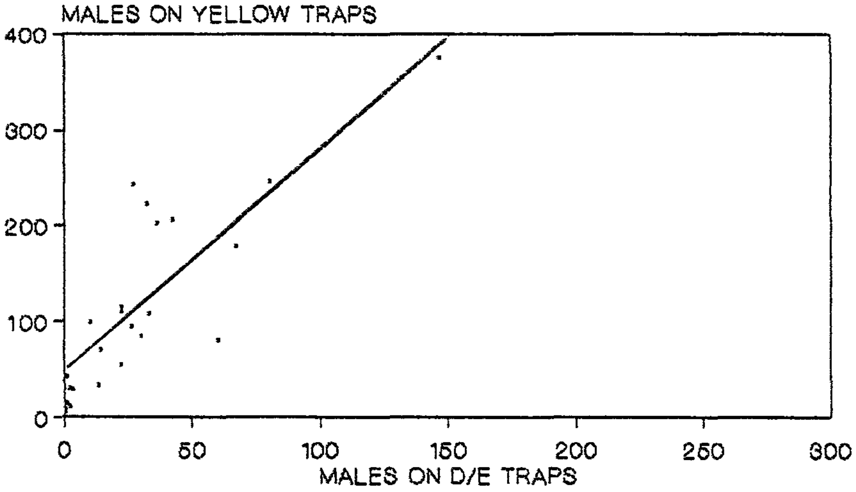


Figure 7.2. The relationship between the monthly numbers of male *S. aurantii* adults recorded on a) 24 D/E traps after emerging and on b) 6 yellow traps. $R^2 = 70.4\%$, F-Ratio = 52.3, $y = 2.42x + 41.57$, $P < 0.001$.

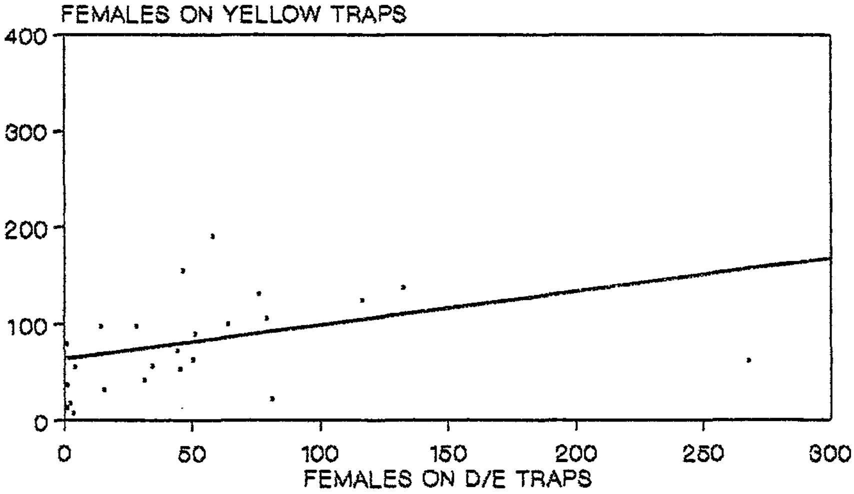


Figure 7.3. The relationship between the monthly total numbers of female *S. aurantii* adults recorded on a) 24 D/E traps after emerging and on b) 6 yellow traps. $R^2 = 7.7\%$, F-Ratio = 1.8, $y = 0.23x + 66.25$, $P = 0.19$.

citrus orchard than females. This is especially true when sex ratios are considered. The majority (64.3%) of the population emerging from pupae were females, whereas only 40.9% of the thrips recorded on the yellow traps over the same time period were of this sex. The yellow traps bias towards male catches was confirmed by the Mann-Whitney paired test comparing the monthly proportions of males caught with that on the D/E traps ($n = 18$ pairs, 17 positive differences & 1 negative, $Z = 3.54$, $P < 0.001$). In 6 of the 24 months less than 10 thrips were recorded by the D/E traps and these were excluded from the analysis.

The weekly totals of thrips caught by each method (including larvae on the D/E traps) are compared in figures 7.4, 7.5 and 7.6. Looking first at the results from September 1986 - May 1987 (figure 7.4), it can be seen that four peaks of thrips were recorded by each trap type from September to December, the timing of the first three peaks being roughly coincident on the two trapping media, whereas in December, the D/E traps recorded a peak slightly earlier than the yellow traps. During January and February, the numbers of thrips caught on the D/E traps was comparatively low. Two peaks can be seen in the results of both trap types, although those of the D/E trap are not very well-defined. At the end of April the last peak is recorded.

In the next sampling period from June 1987 - January 1988, numbers of thrips emerging during June and July were negligible (see chapter 6 and figure 7.5). In comparison, the yellow traps show a slowly declining population throughout these months. There was therefore, in effect, no recruitment to the adult population flying in the area due to a lack of food and oviposition sites, and the yellow traps recorded the decline of numbers of

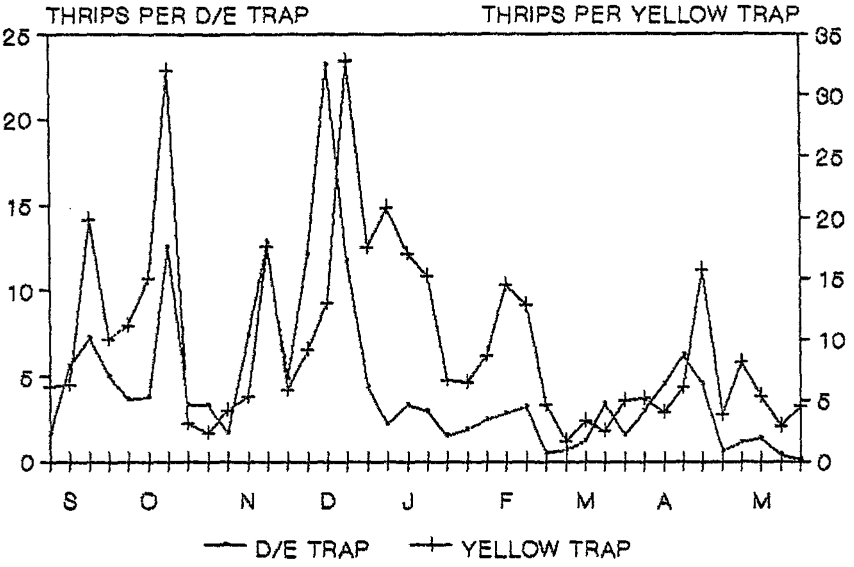


Figure 7.4. Weekly comparison of numbers of *S. aurantii* (larvae and adults) recorded on D/E traps with adults recorded on yellow traps, September 1986 - May 1987.

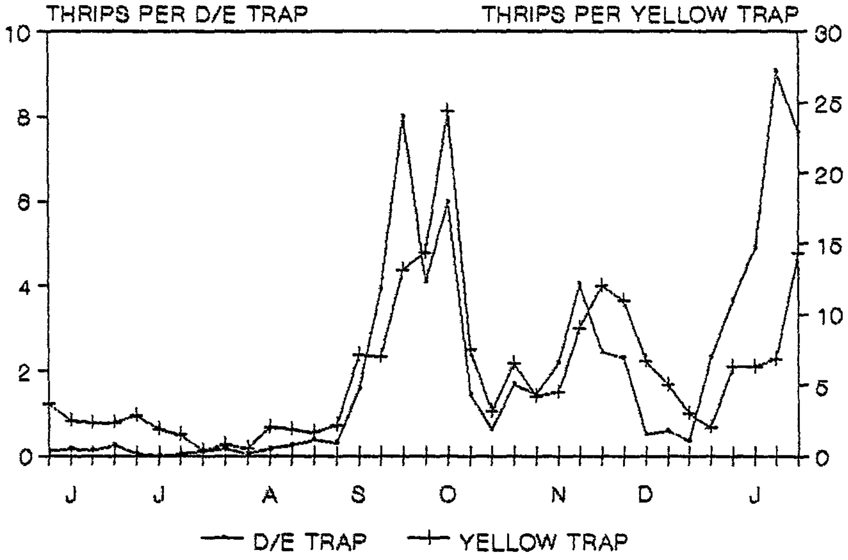


Figure 7.5. Weekly comparison of numbers of *S. aurantii* (larvae and adults) recorded on D/E traps with adults recorded on yellow traps, June 1987 - January 1988.

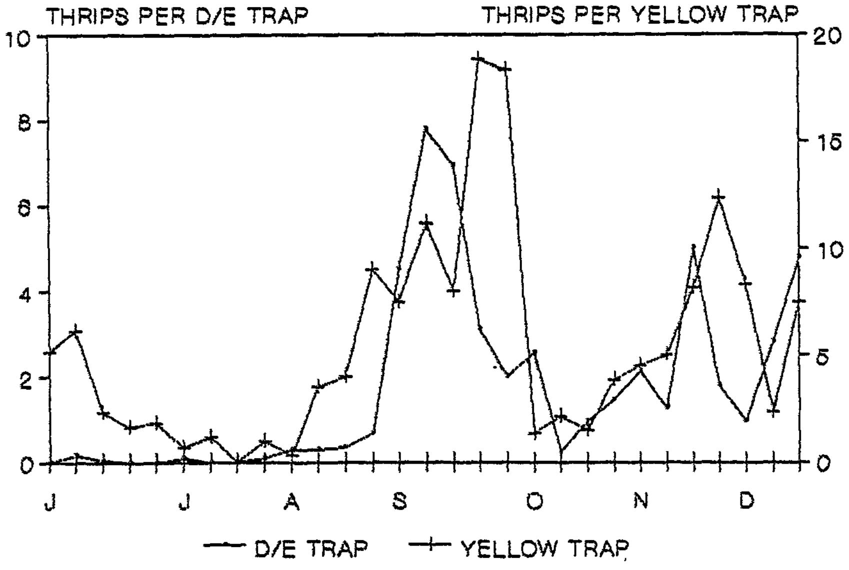


Figure 7.6. Weekly comparison of numbers of *S. aurantii* (larvae and adults) recorded on D/E traps with adults recorded on yellow traps, June - December 1988.

Table 7.2 A comparison of numbers of male and female *S. aurantii* caught a) on D/E traps after emergence from the soil and b) on sticky yellow traps, in relation to the flushing cycle of citrus. X^2 values refer to a comparison between the proportions of males and females recorded by the different trapping methods.

Time Period	Flush	a) D/E Traps Males	Females	% Males	b) Yellow traps Males	Females	% Males	X^2	P	Male bias on D/E or yellow trap (Y)	
08/09/86 - 22/09/86	#1	15	20	42.8	173	22	88.7	41.81	<0.001	Y	***
29/09/86 - 27/10/86	-	98	155	38.7	265	163	61.9	34.32	<0.001	Y	***
03/11/86 - 08/12/86	#2	73	90	44.8	235	32	88.0	93.07	<0.001	Y	***
15/12/86 - 29/12/86	-	143	260	35.5	325	55	85.5	203.69	<0.001	Y	***
05/01/87 - 19/01/87	#3	20	30	40.0	205	113	64.5	10.89	<0.001	Y	***
26/01/87 - 02/03/87	-	29	74	28.2	91	232	28.2	0.00	1.00	-	
09/03/87 - 13/04/87	#4	23	50	31.5	62	68	47.7	5.03	0.02	Y	*
20/04/87 - 27/07/87	-	17	64	21.0	124	258	32.5	4.15	0.04	Y	*
03/08/87 - 21/09/87	#1	9	16	36.0	97	42	69.8	10.58	<0.001	Y	***
28/09/87 - 21/12/87	-	103	181	36.3	411	317	56.5	411.00	<0.001	Y	***
28/12/87 - 25/01/88	#2	28	70	28.6	77	70	52.4	13.61	<0.001	Y	***
01/02/88	-	33	50	39.8	20	66	22.7	5.34	0.02	D/E	*
13/06/88 - 01/08/88	-	1	3	25.0	19	95	16.7	0.19	0.66	D/E	N.S
08/08/88 - 19/09/88	#1	4	5	44.4	171	48	78.1	5.48	0.02	Y	*
26/09/88 - 31/10/88	-	59	109	35.1	176	125	58.5	23.52	<0.001	Y	***
07/11/88 - 05/12/88	#2	13	27	32.5	136	67	67.0	16.76	<0.001	Y	***
12/12/88 - 26/12/88	-	23	39	37.1	56	53	51.4	3.24	0.07	Y	N.S.
Totals	Flush	185	308	37.5	1156	462	71.4	185.51	<0.001	Y	***
	No Flush	506	935	35.1	1487	1364	52.2	111.78	<0.001	Y	***
	Combined Total	691	1243	35.7	2643	1826	59.1	294.99	<0.001	Y	***

overwintering thrips as the population aged. As in the previous sampling period, peaks of thrips recorded on both trap types during spring and summer were well synchronized, although the peak at the end of November was recorded one week earlier on the D/E traps than on the yellow traps.

In June and July 1988, a similar pattern was recorded as in 1987 (figure 7.6). Almost no citrus thrips were recorded on the D/E traps due to a lack of feeding and breeding sites (see chapter 6), and the population as recorded by yellow traps showed a general decline to a minimum at the end of July. The peaks during September and October were not as well synchronized as in previous years. The D/E traps recorded a well-defined peak during late September, two weeks ahead of the major peak recorded on the yellow traps.

Results of the two trap types in relation the phenology of the citrus trees.

A comparison of the numbers of adults caught by the two different trap types in relation to the flushing periods of the citrus is shown in table 7.2. During flush periods as a whole, 37.5% of the thrips emerging were males, but the yellow traps recorded 71.4% males. When the trees were not flushing, 35.1% of thrips emerging were males while the yellow traps recorded 52.2%. Thus, whether the trees were flushing or not, the proportion of males caught on the yellow traps was significantly greater overall than among thrips emerging from the ground ($P < 0.001$).

Table 7.3 The proportion of male and female adult *S. aurantii* caught on D/E traps and yellow traps in relation to tree phenology, during the 24-month experiment. Phenology categories are defined in the methods section of chapter 7. Letters after percentages refer to the results of X^2 analyses of proportions of each sex caught in the different phenology categories <u>within</u> each trapping method. Categories followed by the same letter <u>do not</u> differ significantly ($P > 0.05$). For comparison of results <u>between</u> trapping methods see table 7.4.

		D/E trap			Yellow trap		
Phenology Category	Weeks	Males	Females	% Males	Males	Females	% Males
Critical & Flush (CF)	37	162	258	38.57 a	1094	394	73.52 a
Critical & No Flush (C & NF)	33	466	810	36.52 ab	1290	821	61.11 b
Post-Critical & Flush (PC & F)	6	23	50	31.51 abc	62	68	47.69 c
Post-Critical & No Flush (PC & NF)	27	40	125	24.24 c	197	543	26.62 d
TOTAL		691	1243	35.73	2643	1826	59.14

Many of the individual flush or non-flush periods recorded a similar male excess on the yellow traps. However, all eight individual flush periods had a significant male bias on yellow traps, whereas this was not the case in four of the nine non-flush period (table 7.2).

Looking at this in greater detail, eight flush periods occurred during the duration of the experiment and the expectation that yellow traps would catch a higher percentage of males than the D/E traps in a given flush period was significantly proved using the Mann Whitney paired test (n = eight positive pairs, Z = -4.07, P < 0.001). Not only was the percentage of males caught on the yellow traps always higher than that on the D/E traps during flushes, but also comparison of the proportions of males and females caught on the two trap types during each of the 8 flush periods revealed that it always significantly higher. Between flushes, the yellow traps recorded a higher male percentage in six, a lower percentage in two, and an equal percentage in one, out of nine time periods (Mann-Whitney paired test, Z = -1.90, P = 0.06). Clearly, the likelihood of yellow traps being biased towards males is less between flushes than during flushes.

Comparisons of counts during the four phenology categories introduced in the methods section are summarised in table 7.3. Considering the D/E traps alone, the highest percentage of males in the emerging population (38.57%) was recorded during the C& F period, but this was not significantly different from results obtained during the C & NF or PC & F periods. The lowest percentage (24.24%) was recorded during the PC & NF period and this was significantly different to the C & F, and C & NF categories (table 7.3). Considering the yellow traps alone, the

Table 7.4 Comparison of male *S. aurantii* bias in the weekly catches by yellow and D/E traps at different phases of the phenological cycle. Weeks in which one or other trapping method recorded < 5 thrips were not included in the analysis.

Phenology Category	Food Source(s) for *S. aurantii*	Total Weeks	% males Yellow > D/E	% males D/E > Yellow	Weeks with < 5 thrips (not used).	Mann Whitney Paired Test		
						Z	P	
a) Critical & Flush (C & F)	Young leaves (Flush #1), then small fruit & young leaves.	37	19	1	17	-5.6	< 0.001	***
b) Critical & No Flush (C & NF)	Small fruit.	33	24	5	4	-4.9	< 0.001	***
c) Post-Critical & Flush (PC & F)	Young leaves, & large fruit (only until harvest).	6	4	0	2	-2.5	0.01	**
d) Post-Critical & No Flush (PC & NF)	Large fruit (until harvest).	27	3	4	20	0.44	0.66	N.S.

proportions of males and females caught in the four different phenology categories all differed significantly from each other ($P < 0.05$), ranging from 73.52% males during the CF period to 26.62% in the PC & NF period.

The results recorded by the two different trapping methods within each phenology category can also be compared using the Mann-Whitney paired test. When sample numbers are very low, the possibility of recording extreme percentages is increased. In order to avoid distortion of the analysis therefore, the results were excluded in weeks when one or other of the trap types caught less than a total of five adults. A large number of weeks had to be excluded on this basis, mainly from winter samples when numbers of emerging thrips were low. Nonetheless, sufficient weeks remained for analysis in all four phenology categories (table 7.4). During the CF and C & NF periods, yellow traps showed a bias towards male catches in comparison with the D/E traps in 19 out of the 20 weeks ($Z = -5.6$, $P < 0.001$), and 24 out of 29 weeks ($Z = -4.9$, $P < 0.001$) respectively. This was also true of the PC & F phenology period, (in all four weeks, $Z = -2.5$, $P = 0.01$). Lastly, during the PC & NF period, no significant bias towards male catches was shown. Only three out of the seven weeks suitable for analysis showed a higher percentage of males on the yellow traps ($Z = 0.44$, $P = 0.66$).

Summarizing the results of the different trap types within each phenological category, it was only after the critical period (as defined above) and when the trees were not flushing that yellow traps did not show a significant bias towards towards catching males. During the critical period, regardless of whether the trees were flushing or not, and also after the critical period when flushing occurred, the yellow traps were biased towards catching males.

DISCUSSION

The relative insensitivity of D/E traps can be attributed to a number of factors. Firstly, the two types of trap work in completely different ways. The D/E trap is "passive" in that the trapping surface is transparent. Thrips are caught as they fall onto the trap from above or emerge from below and are therefore in no way attracted to it. The yellow trap on the other hand is an "active trap" as its colour has been shown to be attractive to *S. aurantii* (Samways et al 1986). Furthermore, because of its position on the outer canopy of the tree, thrips are probably attracted not only from the tree on which it is hung but also from other nearby trees as well. In other words the effective area from which thrips are sampled is far greater with a yellow trap than with a D/E trap. In addition, yellow traps may catch thrips of varying ages from just-emerged individuals to relatively old specimens, whereas the D/E trap can catch mature larvae, but only just-emerged individuals.

Despite the difference in sensitivity, the peaks recorded by both trap types were generally very closely synchronized when all life-stages were included (see previous figures), and points to endogenous (within the orchard) build-ups of *S. aurantii* rather than immigration from surrounding uncultivated plants. This supports the conclusions of chapter 3 in which the numbers of citrus thrips in citrus orchards were found to be generally higher than in surrounding bush. Although numerous examples exist of Thysanoptera as invasive pests of crops (Lewis 1973), in many cases these are annual crops, where there is only limited time for thrips to invade and cause damage before harvesting takes place. In the case of citrus, the semi-permanence of the plantings enables long-term associations between the trees and pests to develop (Carman 1989), and the synchronization of the results from the different trap types illustrates such an association.

Comparing the sex ratios recorded on each trap type, the yellow traps were shown to be biased towards catches of male citrus thrips. This sex comprised only 35.7% of the total number of *S. aurantii* emerging, whereas 59.1% of the thrips caught on the yellow traps were males. Results presented in chapter 6 showed that although there was a slight decline (based on limited data) in the proportion of males in the emerging population as the growing year progressed (see figure 6.3), this was far less pronounced than that recorded on the yellow traps (see figure 5.5). Thus the degree of male bias changed through the annual cycle. In particular, the availability of flush as a food source appears to be an important factor in influencing the degree to which the sexes featured on the yellow traps, although overall a significantly greater proportion of males were caught compared to the D/E traps whether the trees were flushing or not. During flush periods male thrips comprised 71.4% of the total, whereas between flushes this figure dropped to 52.2%. In contrast, emergence of the sexes as recorded on the D/E traps was independent of flushing, males comprising 37.5% and 35.1% during flushing and non-flush periods respectively.

When the availability of both potential food sources (fruit and soft flush) was related to the proportions of male and female *S. aurantii* caught, a more complex picture emerged. The greatest bias towards males on the yellow traps in relation to adults emerging was recorded during the "Critical-Flushing" and "Critical & Non-Flushing" periods when the availability of food would not have been a limiting factor. The spring flush (#1) on citrus is the strongest of the year with numerous new shoots being produced. Subsequent flushes (#2, #3 etc) at Letaba usually consisted of only a few new shoots, leading to heavy infestation by *S. aurantii* and severe distortion of leaf growth. After petal-fall a large number of small fruitlets are available and, as these are vulnerable to damage until the end of January, the conditions for feeding and the number of sites available for oviposition would be particularly favourable.

When only young fruit was available (C & NF) the bias towards males on the yellow traps was less but still significant. It has been mentioned previously that the occurrence of the second flush (which always occurred during the critical period) was usually heavily attacked by *S. aurantii*, even when young fruit was also available, indicating that flush may be to a certain extent a preferred food source. When the fruit was too large to be attacked, but flush (#3 or #4) was available (PC & F), the bias towards males on the yellow traps declined still further but was still significant. At this time the relative flight activity of female *S. aurantii* may have increased in comparison to that observed during the critical period because of the small number of new shoots usually available resulting in competition for resources. Relative female flight activity increased further when food was scarce or undetectable (PC & NF), and the bias towards males on the yellow traps disappeared.

Bedford (1943) observed that males of *S.aurantii* were more active and took flight more readily than did females, and the generally higher percentage of males caught on the yellow traps would seem to be partly a manifestation of this. However it is clear that the relatively greater activity of males is not a constant factor and varies considerably according to the availability of different food sources.

Other examples of differential flight activity of Thysanoptera in relation to the availability of food are known. Putman (1965) found that flight was inhibited in fully-fed ovipositing females of *Haplothrips faurei* Hood. In contrast, immature females were willing to fly, as did mature specimens when food was not available. In flowers of *Calystegia*, Kirk (1985) observed that *Thrips* spp. males were far more active than females. The results of the present study show that, under conditions of food abundance, when the citrus trees were flushing and/or young fruit was present, males were far more willing to fly than females. This held true for any season of the year. This relative inhibition of flight in females was reflected in the increased percentage male catch, which was particularly marked at the onset of a flush period. In contrast, when food for thrips was scarce or undetectable, there was no significant difference in the proportions of the sexes caught whilst flying or emerging. This is similar to the results of Putman (1965) in that a lack of food forced females as well as males to fly in order to search for, and discover, new feeding and oviposition sites.

The observation that the sexes of *S. aurantii* vary in their responses to the yellow trap at different times of the year, depending on the phenology of the citrus trees is not necessarily a disadvantage for monitoring systems. Published thresholds for the use of the traps were calculated without taking account of the sex of the adult thrips caught and therefore function within this framework (Samways et al 1986). Furthermore, a number of pest monitoring methods on citrus e.g. those for Mediterranean Fruit Fly *Ceratitis capitata* (Weidemann) and False Codling Moth *Cryptophlebia leucotreta* Meyr. rely solely on the attraction and trapping of males, whose fluctuations in numbers are than taken to be representative of those of the total population, irrespective of other factors (Georgala 1988, Aschenborn & Catling 1978).

From the practical perspective, when using yellow sticky traps, the separate recording of males and females of *S. aurantii* provides a measure of host-plant suitability for egg-laying, and therefore for future population increases. It also provides information on how thrips are interacting with the citrus at any given time of the year. Koppa (1969b) proposed that sample sex ratios of thrips in general could be used as a measure of the suitability of their host plants. The results presented above are analogous to this idea in that a high percentage of male flight activity indicates favourable conditions for breeding and egg-laying on the citrus. This would be of benefit to any citrus grower who takes the trouble to separate males and females in his trapping results.

Which trapping system would be the best to use in a commercial citrus orchard? There is no doubt that the yellow sticky trap was easier to use. Firstly, it was hung at an easily accessible height, whereas the D/E trap had to be installed under the tree canopy; a little inconvenient when the skirt of the tree was low. Hung far from ground level, the yellow trap was not affected by silt which sometimes obscured the upper trapping surface of the D/E trap after heavy rain (see chapter 6). Similarly, the yellow trap was far less prone to be covered with petals during the blossom period. In the case of the D/E trap, this made counting of larvae on the upper surface difficult at this time of year.

With a little practice, adult *S. aurantii* could be told apart with absolute certainty from all other species on the yellow traps. With the D/E trap, larvae of *T. tenellus* could not be distinguished with certainty from those of *S. aurantii*. This however was not a major problem at Letaba as the relative numbers of the two species that emerged indicated that *T. tenellus* was present in comparatively low numbers. This may not be the case elsewhere.

As a result of its ability to sample over a wider effective area (see above), the yellow trap was the more sensitive of the two types despite the fact that the D/E trap could trap larvae as well as adults. The yellow trap was biased towards males for much of the year (despite males forming only a minority of the adult population as measured from the D/E traps), but the peaks of activity recorded on both types were very similar in their timing. It is known from other thrips species that immature females are more prone to flight than mature or gravid individuals (Lewis 1959a, Putman 1965). It may therefore be that female *S. aurantii* are more likely to be caught by a yellow trap directly after emerging than when they are sexually mature. This would allow the traps to record population peaks at similar times to those recorded on the D/E trap. This is probably why, as numbers of trapped thrips increased on approaching a peak, the percentage of males decreased.

On a citrus farm, the yellow trap would yield results more easily than the D/E trap. With a little practice, it is possible for spot check counts to be done with a hand-lens while the yellow trap is hanging in the tree. Despite its practical disadvantages for routine population monitoring, the D/E trap gave a fascinating insight into the movement of *S. aurantii* to and from the soil beneath the citrus trees. If the prepupal and pupal stages were of longer duration, this type of trap would be extremely useful as the occurrence of larvae on the upper surface would serve as a reliable predictor of future adult emergence. The longer the prepupal and pupal stages of the insect to be monitored, the greater would be the value of such a trap. As it was, the subterranean stages of *S. aurantii* were of such short duration that peaks of larval and adult activity were in most cases effectively coincident. Cycling of the traps at a shorter interval than the seven days used in the experiment would increase the predictive ability of the system for *S. aurantii* monitoring, but this necessarily increases the work effort involved. In California for example, D/E traps for monitoring of *S. citri* are cycled every three to seven days depending on the time of year (Cox 1977).

However, particularly for research work on *S. aurantii*, it is felt that the D/E trap could be of considerable use as it yields information that the yellow trap cannot. For example, it could be used to measure the effectiveness of insecticides applied to the soil in efforts to control the prepupal and pupal stages of *S. aurantii*. In such an experiment, D/E traps would only measure adults that had emerged from beneath each specific tree. The effects of insecticide applications on small experimental plots would therefore be more accurately measured and the effects of movement of adults between adjacent trees would be eliminated.

8. THE MANIPULATION OF ORCHARD IRRIGATION AND ITS EFFECT ON THE FLUSHING RYTHMN OF CITRUS TREES AND THE MAGNITUDE OF THE CITRUS THRIPS POPULATION.

INTRODUCTION

Among other things, the observations described in chapter 5 showed that between 1984 and 1990 the autumn growth flush of the citrus trees in the experimental orchard varied considerably in its timing. Consequently, the times when food was available to *S. aurantii* varied and this was reflected in the populations during autumn and winter. Furthermore, there was a relationship between the size of the adult winter population and that found in spring, when population sizes are of economic importance. It was also shown that the distribution of rainfall during the first four months of each calendar year, by influencing the timing of flushing and hence the food supply during autumn, was significantly correlated with the number of citrus thrips which overwintered.

After the cessation of the long-term monitoring part of the study, an experiment was carried out in 1991 in one half of the experimental orchard to simulate the occurrence of unseasonal rainfall. Specifically irrigation in late autumn was used in an attempt to stimulate an abnormally late flush. The citrus thrips populations in the irrigated (late-flushing) and stressed halves of the orchard were then monitored separately throughout late autumn and winter.

In 1992, a similar experiment was carried out to investigate the effect of delaying the application of irrigation (and consequently the appearance of the spring flush) on the numbers of *S. aurantii* in the two halves of the orchard.

METHODS

As mentioned in chapters 3 and 5, navel orchards at Letaba receive minimum irrigation during autumn and winter. In order to investigate experimentally the effects of simulated rainfall on the flushing rythmn and hence thrips numbers, two groups of trees within the experimental orchard were subjected to differing irrigation practices. From the third week of April 1991, one group of 50 trees was irrigated twice-weekly in an effort to promote an out-of-season flush. The rest of the orchard received irrigation sufficient only to prevent severe wilting and leaf-drop. Induction of a light wilt through moisture stress in navel orchards is normal practice at Letaba after the oranges have been harvested.

A yellow sticky trap was placed on each of six trees at the centre of the "irrigated" group so that thrips numbers could be monitored. The height and orientation of the traps was similar to that described in chapter 2. Similarly, a yellow trap was placed on each of six trees in the "stressed" half of the orchard. Changing of the trapping surface took place every seven days and the trapped thrips were then counted. In this way, a comparison could be made between thrips numbers in the two parts of the orchard.

In 1992, the layout of traps in the orchard was exactly the same as in 1991. In one half of the orchard, irrigation was applied normally, which induced a flush beginning in late July. In the other half of the orchard, irrigation was withheld for a further number of weeks to delay the onset of the spring flush. Citrus thrips were counted on the yellow traps on a weekly basis as before.

RESULTS

In 1991 it was not as easy as was hoped to induce a strong late flush. A twice-weekly irrigation was only sufficient to induce a very sparse flush of between two and five shoots per tree, and a very few out-of-season blossoms. The flush lasted from the middle of May to the middle of June. Nevertheless, these few shoots were heavily attacked by *S. aurantii*.

During the time that the induced flush remained soft, counts of adult thrips in the irrigated and non-irrigated halves of the orchard followed roughly the same trend (figure 8.1, Mann Whitney paired test on weekly counts showed no significant difference $Z = -1.70$, $P > 0.05$). However, from early June (as the flush was beginning to harden off) until the end of winter, the yellow traps in the irrigated half of the orchard consistently recorded greater weekly numbers of *S. aurantii* ($Z = -4.5$, $P < 0.001$).

In both halves of the orchard, the numbers of *S. aurantii* recorded on the yellow traps increased considerably in the latter half of August as the usual spring flush (#1) began to harden off. However, the traps in the half of the orchard where the

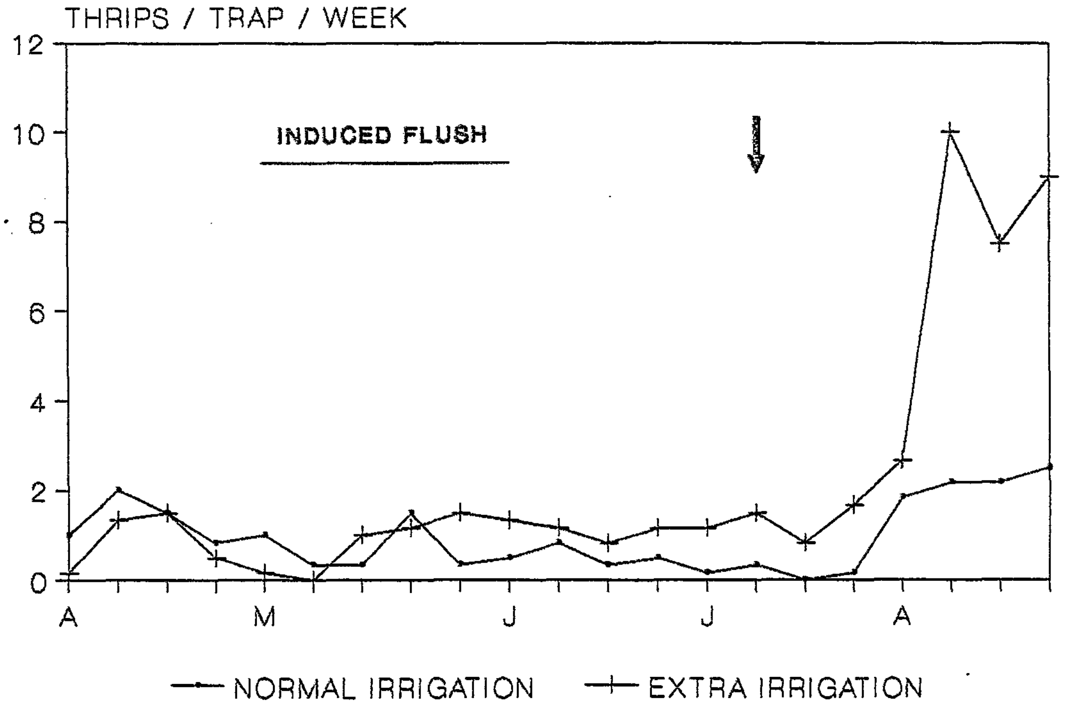


Figure 8.1 Weekly numbers of *S. aurantii* recorded on yellow traps, and the timing of flush periods of the trees, in two halves of a citrus orchard, from mid-April to early September 1991. In one half of the orchard (+), extra irrigation was applied to induce an additional flush as indicated. In the other half (•), normal irrigation practice was followed (see text). Arrow indicates emergence of normal spring flush (#1) in both halves of orchard.

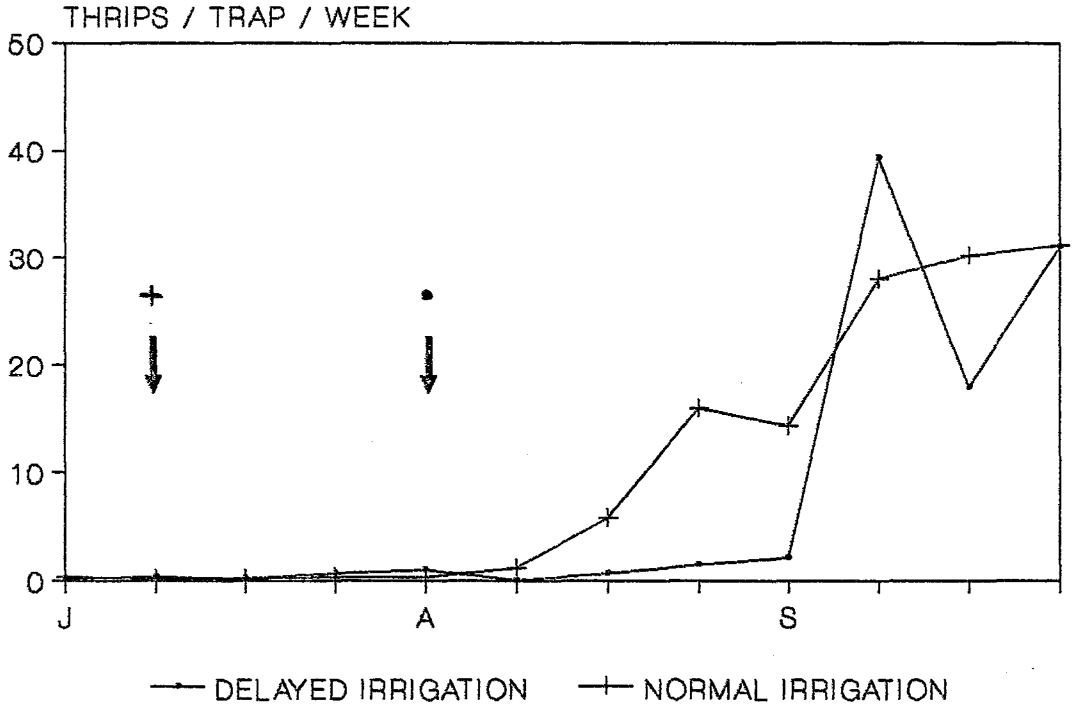


Figure 8.2 Weekly numbers of *S. aurantii* recorded on yellow traps, and the timing of flush periods of the trees, in two halves of a citrus orchard, from mid- July to early October 1992. In one half of the orchard (+), normal irrigation practices were followed. In the other half (•), irrigation was not applied until early August delaying the onset of the spring flush. Arrows with symbols indicate emergence of spring flush in the relevant halves of the orchard.

extra flush had earlier been induced recorded far higher numbers of citrus thrips than the half in which no late flush or out-of-season fruit had been stimulated.

The results from 1992 are shown in figure 8.2. In the half of the orchard which received a normal irrigation schedule, numbers of *S. aurantii* remained extremely low until the latter half of August when numbers began to increase, reaching in excess of 15 thrips per trap in early September. In contrast, in the half of the orchard where irrigation was withheld and flushing delayed until mid-August the adult population during late August and September was far lower than in the normally irrigated part of the orchard. However, by late September and early October the population here increased dramatically reaching levels in general similar to those found in the other half of the orchard.

DISCUSSION

In 1991 greater numbers of *S. aurantii* were able to overwinter in the half of the orchard in which a late autumn flush and out-of-season fruit was stimulated by higher than normal irrigation, a confirmation of the earlier observations of chapter 5. Despite the cooler winter weather, *S. aurantii* was able to utilize a food source to maintain it's population at a higher level throughout winter. In addition, the population increase which occurred at the end of the first flush was far greater in the half of the orchard where out-of-season fruit had been available as a food source in winter. The higher overwintering population there would, at the end of July with the onset of the "spring flush", have been able to lay a larger number of eggs than the relatively low population in the "stressed" half of the orchard. This would have given rise to higher numbers of larvae developing on the spring flush and later descending to the ground to pupate. Subsequently the emerging adult population was larger in this half of the orchard.

Despite the danger that too much irrigation can stimulate flushing during late autumn and winter at Letaba, it is nevertheless necessary to maintain the tree in a healthy condition during this time of the year. The excessive withholding of irrigation carries with it the danger of roots drying out and dying with consequent loss of tree condition. As rainfall in winter at Letaba is usually low, irrigation therefore remains indispensable. In practice orchard management aims to supply as little water as possible to satisfy the two aims of maintaining tree health but avoiding the production of vegetative growth in winter.

The results of 1992 confirmed that the timing of the spring flush was very important in governing the timing of the initial population increase of *S. aurantii* adults in spring. It should be remembered that the hardening of the first flush coincides with the end of blossoming and the consequent exposure of small fruitlets on the tree. In chapter 6 it was seen that, at the end of the first flush of the growing season, large numbers of second instar larvae descended to the ground. Where the onset of the spring flush was delayed through the withholding of the irrigation, *S. aurantii* adult numbers remained lower for a number of weeks longer than where the flush was induced at the normal time. This further supports the results of chapter 3 where alternative hosts were shown not to be a factor in promoting the spring outbreak of citrus thrips on the crop. If immigration from alternative hosts was important, then one would have expected a general population increase of adults at the same time throughout the whole orchard.

Once thrips became abundant in both halves of the orchard (from late September), the total thrips caught for the next three weeks were approximately the same, although the numbers in the "delayed-flush" half showed greater fluctuation. There was therefore no evidence that the short delay in the induction of the spring flush led to increased or decreased numbers of adult thrips once the flush had hardened off. However the build-up of adult numbers occurred much earlier in the half of the orchard where the trees were more advanced phenologically. The experiment underlines the fact that it is important to be aware of the phenology status of citrus trees, and that control measures for thrips should be applied accordingly and not on a calendar basis.

9. DISCUSSION

Although *S. aurantii* does damage to the vegetative growth of citrus trees causing distortion and stunting of leaves and shoots (Bedford 1943), its main direct economic impact is as a result of cosmetic damage to the surface of the fruit. Every year in the southern African citrus-growing region, large quantities of fruit have to be downgraded or sent for juicing purely because of the cosmetic blemishes on the rind caused by this insect.

The purpose of the present study was to improve knowledge of the ecology of *S. aurantii* so that control of the pest in citrus orchards in South, and southern, Africa might be improved. Ideally, the discovery of an important natural enemy would have been included in such a long-term study. Unfortunately this did not arise. It was clear that at Letaba, in an orchard where no chemical control measures were applied for thrips or other citrus pests, severe thrips damage was the norm in most years. No evidence of parasitism of larvae or adults was ever seen, and bearing in mind that *S. aurantii* is indigenous to the region, the finding of a parasitoid locally in the future is unlikely. Similarly, *Scirtothrips citri* in California has no known parasitoids (Tanigoshi & Nishio-Wong 1982), and no literature regarding biocontrol could be found for *S. dorsalis*.

However, in the eastern Cape region of South Africa, a predatory mite *Euseius addoensis addoensis* seems to be suppressing citrus thrips numbers (Grout & Richards 1992). Although a closely related species of predacious mite *Euseius citri* has in the past been identified on the estate, it does not seem able to give any significant degree of control of *S. aurantii* at Letaba. The lack of biocontrol of *S. aurantii* was in stark contrast to the situation regarding scale insects and mealybugs which, in the experimental orchard, were kept under very good biological control due to the activities of their efficient natural enemies. Chemical disruption of *S. aurantii* biocontrol is therefore not an issue at Letaba at present, but nonetheless it is dangerous to pursue its control oblivious of the consequences on the natural enemies of other pests, because of the potential of secondary pest repercussions.

The damage caused by *S. aurantii* has assumed greater importance in recent years. An increase in insect and/or mite damage can be caused on a particular crop as a result of pest recruitment as the area under cultivation increases (Strong et al. 1984). This is at present happening in the avocado industry of South Africa, which is rapidly expanding (Dennill & Erasmus 1992). However, citrus has been grown on a large scale at Letaba for over 60 years, and is therefore not a newly-established crop on the estates. In the present study, when examining the population fluctuations of *S. aurantii* throughout the year using yellow traps to catch adults, there were no long-term trends evident. Years with high total numbers could be followed with those with low numbers and vice-versa. There was therefore no evidence that the increasing importance of citrus thrips was as a result of annual increases in the incidence of the pest. Rather, it is probably related to the changing market forces discussed below.

Two factors are leading to increased pressure on growers to produce unblemished ("clean") fruit, thereby necessitating a more efficient thrips control programme. Firstly, over the past few years, the amount of blemish allowed on export-quality fruit has been reduced to improve the external appearance of overseas shipments. Southern African citrus fruit has to compete, particularly in the European market place, with fruit from citrus-growing regions (such as those of South America) where *S. aurantii* is absent, and the problem is aggravated when the marketing of fruit from the different regions overlaps. Inevitable comparisons are then drawn by wholesalers and consumers between fruit from the various producing countries.

Secondly, in recent years a price premium has come to be placed on large rather than small sized citrus fruit. In certain years, it is not worth exporting the smaller fruit as the final market price is too low, despite the fact that the external appearance may be completely unblemished. In an attempt to overcome the consequent drop in export volumes, (measured by growers as a percentage of the total crop), increased emphasis is placed on pest, and particularly thrips, control to preserve as many of the more valuable large fruit in an unblemished condition and to maintain, as far as possible, the export volumes of the past.

In this study, despite the fact that *S. aurantii* is known to be polyphagous (Faure 1929) and that the presence of a number of alternative host plants next to the experimental orchard was confirmed, no evidence was found that such hosts at Letaba were important in promoting outbreaks of the pest on the citrus after blossoming. During the first few weeks after petal-fall, (during late September and October), numbers of *S. aurantii* in bush adjacent to the experimental orchard were extremely low in comparison to the numbers trapped within the orchard. Although, during November and December in one particular year, larger numbers of *S. aurantii* were found on traps placed in bush, there was no convincing evidence of large-scale movement of thrips from alternative host plants into the orchard. In addition, comparison of the results of trapping of mature second instar larvae and emerging adults on D/E traps and adults on the yellow traps showed very similar timing of peak numbers, further supporting the endogenous build-up of thrips numbers rather than immigration as the dominant source of population increase. This contrasts strongly with the case of *Isoneurothrips australis* Bagnall, where large numbers of adults were observed in a *Eucalyptus* tree at the beginning of the growing season by Laughlin (1970) before larvae were subsequently trapped falling to the ground, indicating considerable immigration.

Bearing in mind that citrus is regularly irrigated for the setting of a commercial crop, whereas the only source of water for alternative host-plants is rainfall (which is usually low at Letaba in winter and early spring), early in the growing season conditions for *S. aurantii* population increase are therefore far more favourable on citrus than on other plants. Failure to control an outbreak of citrus thrips at, or soon after, petal-fall is therefore unlikely to be due to mass immigration of individuals from nearby uncultivated hosts. This is perhaps atypical of the traditional picture of Thysanoptera being invasive pests (Wolfenbarger & Hibbs 1958, Laughlin 1970, Lewis 1973), although immigration onto crops is not always important (Harding 1961). In the event of a failure to control *S. aurantii*, particularly soon after blossoming, the spray practices of the grower should therefore be examined rather than the blame placed on pest invasion from alternative host plants.

Nevertheless, if a grower wished to monitor citrus thrips using sticky yellow traps in an area of uncultivated vegetation adjacent to his citrus orchards, the results of the present study (and others) would allow, with a little practice, distinction to be made between individuals of *S. aurantii* and the three other thrips species of similar appearance found during the course of the study. *T. tenellus* was relatively easy to distinguish from *S. aurantii* and a key was published previously by Samways et al. (1986). *S. fulleri* was sometimes very common on traps placed in the bush habitat, and would be the species most likely to be confused with *S. aurantii*. Reference to Faure (1929) would enable these two *Scirtothrips* species to be told apart. The third species was an unexpected discovery, - *S. dorsalis*, not previously recorded from Africa. Interestingly it was found at Letaba on the Castor Oil plant, *R. communis*, a known host of this thrips in other countries (Hood 1919, Ananthakrishnan 1973). Despite it being a pest of citrus in Asia (Mound & Palmer 1981), the presence of *S. dorsalis* on citrus fruit at Letaba could not be confirmed at the time of writing.

As regards population monitoring, the almost continuous presence of *S. aurantii* in the experimental orchard, revealed by weekly trapping over the six-year monitoring period of June 1984 to May 1990, was a demonstration of the long-term association which a pest can develop with a semi-permanent crop such as citrus (Carman 1989). This is in contrast to an annual crop where, in the absence of growth remaining from the previous season, pests have first to locate the new planting before advantage can be taken of the newly-discovered food source. Furthermore, only a limited amount of time exists for pest population increase on an annual crop before harvesting occurs and the food source is removed. At Letaba, *S. aurantii* does not have to discover the citrus plantings, but is a permanent resident.

The traditional picture of thrips numbers declining after April to a minimum during winter (Wentzel et al 1978) was not always found to hold true at Letaba. It seems as if there is no really unfavourable season for citrus thrips in this area, and this contrasts strongly with the situation that many species of thrips face in temperate regions where severe weather leads to a decline in numbers during winter (Lewis & Navas 1962). In two of the six years studied, (1984 and 1986), *S. aurantii* numbers were found to increase and peak in winter at very high levels. In both these years, a late autumn growth flush had previously been observed along with the setting of out-of-season fruit on the citrus trees, providing a food source not available in the other four years. The thrips was therefore able to exploit unusual leaf production patterns. Certain leaf-miners are also able to achieve this, but by staggering their termination of diapause (Auerbach & Simberloff 1984), clearly not the case with *S. aurantii*. The occurrence of late flushes was associated with relatively high rainfall in March and April compared to that of January and February. This influence was so strong that a direct correlation was found between the degree to which late rainfall occurred and the number of *S. aurantii* adults trapped in winter. Similarly, Davidson & Andrewartha (1948b) found that rainfall during autumn contributed to the increased survival of *Thrips imaginis*. However for *T. imaginis* the rainfall was beneficial by decreasing pupal desiccation, allowing a higher overwintering population to survive, and leading to increased spring numbers.

No correlation was found between the winter weather conditions (temperature and rainfall) and the magnitude of the *S. aurantii* population at that time. At Letaba therefore, the winter climate was found to be too mild to have a direct suppressive effect on the development of thrips. The only climatic factor found governing the magnitude of the overwintering population was the indirect effects of the rainfall stimulating the initiation of atypical flushing patterns on the citrus trees of which *S. aurantii* was able to take advantage. A significant (though non-linear) correlation was also found between the magnitude of the winter population and that of the following spring. It is perhaps not surprising that this relationship was non-linear bearing in mind the strong shift in the sexes caught on the yellow traps between winter and spring from mainly female to mainly male. A significant correlation however was not established between the occurrence of a high late rainfall index (as defined in chapter 5) and the magnitude of the following spring population of *S. aurantii*. This was probably due to the fact that the two parameters were separated by a number of months. Nevertheless the chain of events leading to high spring numbers of the pest are strongly suggestive.

There is no doubt that at Letaba the (unavoidable) practice of limiting irrigation in navel orchards late in the growing season, to prevent poor internal fruit quality and excessive size, makes these trees particularly prone to flushing late in the growing year, if the rainfall pattern is suitable. As new foliage is such an important factor in promoting population increases in *S. aurantii* at any time of the year, more attention should be given to its protection. As mentioned above, late autumn flushes were important in boosting the numbers of thrips which overwintered which, in turn, had a carry-over effect into spring. When a late flush was stimulated artificially by applying abmormally high irrigation, a similar effect was observed, in that the number of thrips overwintering was boosted in comparison to an orchard in which no flush was induced.

Citrus growers in the Lowveld should therefore ideally aim to control thrips on the last flush before winter as this should ultimately lower the numbers of the pest that overwinter. Growers should be particularly wary when high rainfall occurs after a dry January and February, and surveys for new growth and out-of-season blossoms and fruit should therefore be carried out. Any out-of-season fruit should be removed from the trees as soon as possible.

The two types of trap used for the monitoring of *S. aurantii* functioned in very different ways, with consequently varying advantages and disadvantages. However, both recorded peaks of thrips activity at similar times. There is no doubt that the yellow trap was easier to handle and count thrips on, and is thus likely to appeal to a grower more than the Dispersal/Emergence trap. However use of the D/E trap enabled different types of data to be gathered. For example, the mean percentage of each sex in the emerging *S. aurantii* population was established as 35.7% males and 64.3% females, a female-biased sex ratio typical of haplodiploid species (Suomaleinen 1962). Males were found all the year round, although the percentage of males emerging tended to be highest in spring and declined somewhat throughout the growing season. This is in contrast to certain other thrips species such as *Limothrips denticornis* and *Frankliniella tenuicornis* (Uzel), where the males die out during winter (Koppa 1969a).

The mean emergence rate of total *S. aurantii* adults compared to larvae dropping to the ground was 43.7% and no seasonal pattern was evident. As mentioned in chapter 6, the emergence rate estimate may well be too conservative due to the destructive sampling of the second instar larvae by the D/E trap. Nevertheless, it can be seen that if large numbers of larvae are allowed to complete their development on a particular flush, a severe infestation of adults on fruit is likely to subsequently develop. The D/E trap also confirmed that no diapause of *S. aurantii* occurred in winter, as emergence of large numbers of adults in the absence of larvae descending to the ground was not evident.

Unlike the D/E trap, a coloured trap relies on visual cues to attract insects (Prokopy & Owens 1983). Yellow has been shown to be effective in attracting insects which feed on foliage, with the exception of those that feed on grasses (Kirk 1984). An obvious disadvantage of yellow traps is that the presence of *S. aurantii* larvae in the orchard is not revealed. However the economic thresholds calculated by Samways (1986) made allowance for this. There are a number of examples in which the greater activity of male Thysanoptera has been directly observed (Bedford 1943, Kirk 1985), although in some species it is the females which are more active, as in the case of the oat thrips *Stenothrips graminum* Uzel (Lewis 1965). However, trapping does not always reveal sexual differences in flight activity, perhaps because of the short-term nature of the studies (e.g. Kirk 1984). In the present study, because it was carried out over such a long period of time, male and female *S. aurantii* were seen to vary in their apparent flight activity at different times of the year. In insects which have a haplodiploid system of reproduction, ovipositing by unmated females will lead to a shift towards a male bias in the population (Koppa 1969b, Godfray 1988). However, this was found not be the cause of the observed yellow trap male bias, as revealed by the D/E traps. Instead, observations of the phenology of the citrus trees revealed that male flight activity was greater than that of females during times of the year when food in the form of new soft leaves and/or young fruit was available.

The distinction between male and female *S. aurantii* is not difficult (Faure 1929, Samways et al. 1986) and, from a practical point of view, citrus growers which use yellow traps as part of a citrus thrips monitoring system would benefit from the separate recording of the sexes. In many instances, the percentage males on the yellow traps increased at the onset of a flush period on the citrus trees (chapter 5). Consequently, the separate recording of the sexes would enable a grower to be made aware of any change in apparent sex ratio of thrips caught in specific orchards. He could then visit these orchards and judge the phenological state of the trees in the area where the traps are situated. Perhaps ultimately a spray would be applied to protect the new growth, which is important to avoid stunting (Bedford 1979) and crop loss (Kamburov 1991). Furthermore, it is vegetative growth on the citrus trees rather than alternative host-plants that is important in promoting a build-up of thrips numbers. Peaks of larvae falling to the ground at the end of a flush period were closely associated with peaks on the yellow traps, further indicating the desirability of detecting leaf flushes and controlling the citrus thrips thereon. Without the separation of the sexes in the trapping results, the warning of the onset of a flush period would not be apparent without direct observation of the trees.

The control of *S. aurantii* is certainly not going to become easier in the future. Instead, the market forces described above will tend to force thrips control in particular and citrus pest control in general to become stricter. Furthermore, all growers producing fruit for export have to comply with European Economic Community regulations regarding minimum residue levels of pesticides. These regulations can only become stricter in the future, possibly further limiting the choice of chemicals available and/or increasing the time period between application and harvest. Such factors emphasize the need to improve knowledge of the ecology of *S. aurantii*, and indeed all citrus pests. In practical terms, it is very important to know what the phenological state of a citrus orchard is at any time of the year and the numbers of *S. aurantii* which are present. Trapping of citrus thrips should therefore ideally continue all the year round. This is particularly important in young citrus orchards which tend to grow more vigorously than older trees, and provide an especially favourable habitat for thrips.

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