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ASPECTS OF THE BIOLOGY AND MANAGEMENT OF FROGGATT'S APPLE LEAFHOPPER (*TYPHLOCYBA FROGGATTI* BAKER) IN NEW ZEALAND.

A thesis

submitted in partial fulfilment

of the requirements for the Degree

of

Master of Horticultural Science

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university of Canterbury.

by

D. A. J. Teulon

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Abstract of a thesis submitted in partial fulfilment of the requirements for the Degree of M.Hort.Sc.

ASPECTS OF THE BIOLOGY AND MANAGEMENT OF FROGGATT'S APPLE LEAFHOPPER (*TYPHLOCYBA FROGGATTI* BAKER) IN NEW ZEALAND.

by D. A. J. TEULON

Froggatt's apple leafhopper (FALH) is a minor pest of apple in New Zealand although it has the potential to increase its pest status through insecticide resistance and any reduction of insecticide use aimed at 'key pests'. This thesis gathered basic biological information to rationalise any future management of this insect.

Yellow sticky boards were used to sample FALH adults in three orchards under different management regimes and the adults of the egg parasite *Anagrus armatus* in two orchards. Sampling of overwintering eggs, summer eggs and nymphal instars occurred only in an abandoned orchard.

Regular insecticide applications in a commercial orchard reduced the numbers of FALH and *A. armatus* to very low levels compared to those trapped in an abandoned orchard. All life stages of FALH sampled over two seasons in an abandoned orchard strongly suggested the presence of at least two, and possibly a partial third, generation. A similar temporal distribution was found in blackberry adjacent to an abandoned orchard. Overwintering eggs, summer eggs and nymphs showed no consistent preference for any of the examined positions within the tree. Adult numbers trapped on yellow sticky boards increased with height, due to a disproportionate increase of males with height in relation to females.

The description of the pattern of distribution was established using the indices of Taylor's power law and Iwao's patchiness regression for overwintering eggs (randomly dispersed, cohesive groups of eggs), for two seasons of summer eggs (a clumped distribution with a basic component of individuals in both seasons) and two seasons of nymphal instars (basically random or clumped groups of individuals). Of the 27 distributions analysed, Taylor's power law gave the better data fit on 26 occasions. Only four distributions were described differently by the two models.

FALH numbers built up quickly in a previously uninfested orchard through natural increase and migration. Migration over short distances was mainly influenced by the condition of the host plant and the prevailing wind.

Conservative estimates of parasitism by A. armatus were established for overwintering FALH eggs (30-53%) and summer FALH eggs (20-100%) in an abandoned orchard. Yellow sticky board samples indicated that the life cycle of A. armatus was well synchronised with that of FALH.

The appropriate base temperatures for different development stages of FALH were found to be between 9.7 and 11.0°C by laboratory studies and field measurement. A thermal constant of 463.5 ±10.5D° from egg to adult was established from laboratory studies.

Acetate sheets placed on the yellow sticky boards only reduced the spectral reflectance by a small amount but improved sampling efficiency and trap storage. The yellow sticky boards were found to sample larger proportions of the FALH population in relation to the D-Vac (at all densities) and Johnson and Taylor suction trap (only at high densities). Sticky boards appeared to preferentially sample males in relation to females. Higher placement of sticky boards in the tree reduced the number of leafhoppers, other than FALH, caught.

A rational approach to control, based on all available data for this insect, is discussed.

KEYWORDS: Typhlocyba froggatti Baker; Cicadellidae; Typhlocybinae; apple; pest management; sampling; phenology; within tree distribution; dispersion; parasitism; Anagrus armatus (Ashmead); Mymaridae; thermal summation.

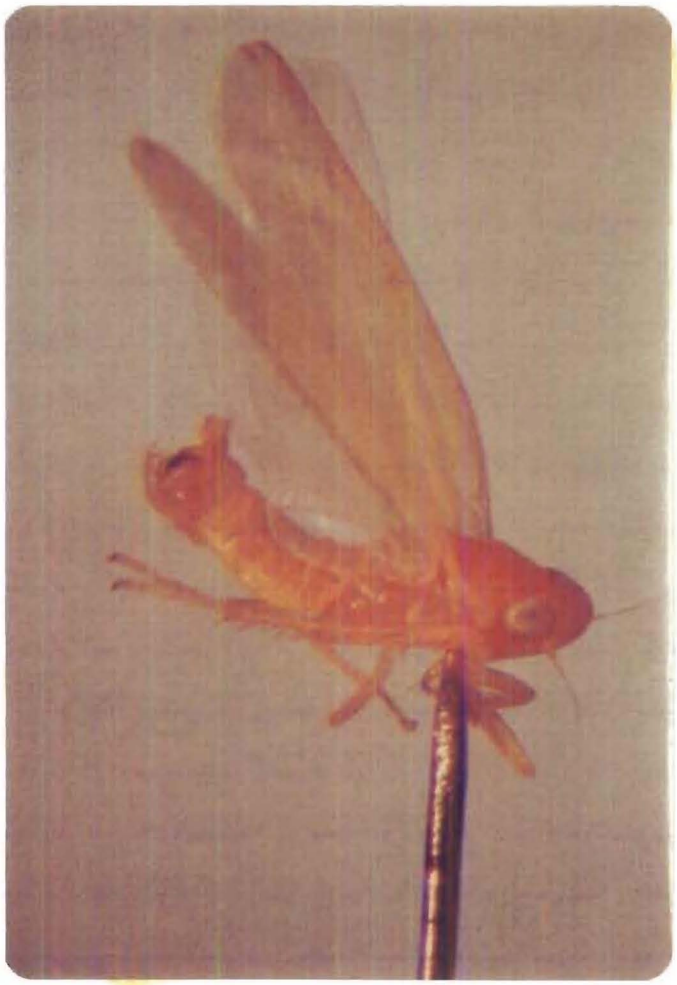

Plate 1: *Typhlocyba froggatti*, male (x15 approx.)

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CHAPTER I.

INTRODUCTION.

The integrated management of insect pests has arisen from a growing awareness of the overuse and overreliance on insecticides for pest control. 'Integrated pest management' (IPM) recognises the limitations of single strategies in pest control and aims to utilise all suitable techniques to reduce and maintain pest populations below those causing economic injury, with minimum disturbance to the environment. In most management situations there is a complex of pests to be dealt with. The life systems of each, as well as an understanding of the ecosystem, need to be established before rational decisions can be made concerning the integrated control of all the pests in that system.

Although of some size, the complex of insect and mite pests of apple in New Zealand is smaller than that of Europe or North America (Collyer and van Geldermalsen, 1975). The key pests, at whom calendar schedule pesticide applications are presently aimed, include codling moth (Laspeyresia pomonella (L.)) and several species of leafroller, including lightbrown apple moth (Epiphyas postvittana (Walker)) (Collyer and van Geldermalsen, 1975). Mite species, including twospotted spider mite (Tetranychus urticae Koch) and European red mite (Panonychus ulmi (Koch)), have more recently become a serious problem due to pesticide-induced resurgence and acaricide resistance (Penman et al., 1979). Other insect species that require control measures include San José scale (Quadraspidiotus perniciosus (Comstock)), woolly apple aphid (Eriosoma lanigerum (Hausmann)) and Froggatt's apple leafhopper (Typhlocyba froggatti Baker) (Collyer and van Geldermalsen, 1975).

Within the last ten years the IPM of apple pests has become a prominent field of research in entomology in New Zealand (Collyer and van Geldermalsen, 1975; Penman et al., 1979), and its importance has not diminished. This thesis is especially concerned with aspects of the biology of Froggatt's apple leafhopper (referred to as FALH in this thesis) which may be termed a minor pest of apple orchards in New Zealand. Under the present pesticide applications aimed at 'key pests'

this insect has been adequately controlled although under certain circumstances, such as occurred soon after its discovery in New Zealand, the insect has been found in economically damaging numbers.

The present equilibrium experienced in New Zealand apple orchards is, as in most intensive horticultural ecosystems, reliant on chemical protection, which is fragile and may at any time change the status of minor pests such as FALH. It is likely that resistance of this insect to commonly used insecticides is imminent. Previously FALH indicated resistance to DDT/DDD (see text) and a similar North American species (Typhlocyba pomaria McAtee) has become resistant to azinphosmethyl on that continent. Considering the high levels of application and the length of time that azinphosmethyl has been used in New Zealand, it is surprising that failure to control FALH has not already occurred. Furthermore, with increasing introduction of IPM strategies it is envisaged that applications of broad spectrum insecticides will be diminished in apple orchards (Thomas, pers. comm.), and therefore the status of minor pests may be altered.

For some time research on the biology of FALH has been neglected, probably due to the success of past and present chemical controls. Therefore, this thesis aims to gather basic biological information that may help in the 'integrated management' of FALH if and when any of the aforementioned outcomes are realised.

The following areas of research were selected:

(i) Extensive sampling, by various methods, of the life stages of FALH; (ii) Preliminary investigation of the effect of parasitism and predation on FALH and; (iii) Determination of the influence of temperature on the development of FALH.

CHAPTER II.

REVIEW OF THE LITERATURE.

The literature on FALH in New Zealand is sparse and only two papers by Dumbleton (1934, 1937) investigate the subject to any depth. Therefore, in this chapter a reasonably broad review of the literature is given with special emphasis on the biology of FALH that could relate to its management, and its damage and economic importance.

2.1 Taxonomy.

(i) Leafhoppers of the subfamily Typhlocybinae.

Following Woodward *et al.* (1970), the suborder Homoptera comprises three divisions: the Coleorrhyncha, the Sternorrhyncha and the Auchenorrhyncha. The superfamily Cicadelloidea belongs to the Auchenorrhyncha and is considered to be most closely related to the Cicadoidea (Evans, 1966). The subfamily Typhlocybinae is grouped within the Cicadellidae which is the dominant family of the Cicadelloidea.

According to Knight (1976) this cosmopolitan subfamily was represented in New Zealand by only 13 species in 6 genera. Leafhoppers in this study that belong to this subfamily include: *Zygina dumbletoni* Ghauri; *Zygina zealandica* (Myers); *Typhlocyba froggatti* Baker; *Typhlocyba lethierryi* Edwards; *Ribautiana tenerrima* (Herrich-Schaffer) and *Eupteryx melissae* Curtis.

(ii) *Typhlocyba froggatti* Baker.

This species was first described by Froggatt (1918) from New South Wales Australia, under the name *Empoasca australis*. It was independently described by DeLong (1926) as *Empoa* (*Typhlocyba*) *malini* and McAtee (1926) as *Typhlocyba xanthippe* from North America, and by Ribaut (1931) as *Typhlocyba oxyacanthae* from Europe.

Over a period of time, like most insects, the nomenclature of this leafhopper has been in doubt. Metcalf (1968) gave eight different synonyms:

Empoasca australis Froggatt (1918),
Typhlocyba australis (Froggatt). Myers (1921),
Typhlocyba froggatti Baker (1925),
Empoa (Typhlocyba) malini DeLong (1926),
Typhlocyba xanthippe McAtee (1926),
Typhlocyba oxyacanthae Ribaut (1931),
Edwardsiana froggatti (Baker). China (1950) and
Edwardsiana australis (Froggatt). Christian (1953).

Most recently Knight (1976) confirmed Typhlocyba froggatti Baker as the correct name.

(iii) Common names.

Similarly, Typhlocyba froggatti Baker has been known under several different common names. Originally 'apple leaf jassid' was used by Froggatt (1918) and later by Noble (1929) and Kemp (1938). 'Australian apple leafhopper' was used by Myers (1921, 1923) and this was later shortened to 'apple leafhopper' by a number of Australasian authors including: Noble (1929), Dumbleton (1934, 1937), Evans (1935, 1940a), Ward (1936, 1938), Jenkins (1943), Jenkins et al. (1950) and Cottier (1956). Evans (1940a) also and Miller (1949) referred to this species as 'canary fly'. In North America, DeLong (1931) suggested the common name of 'yellow apple leafhopper'.

Ferro et al. (1977) made an attempt to standardise common names of econmically important terrestrial invertebrates and other commonly encountered species in New Zealand. In their paper 'Froggatt's apple leafhopper' was designated the common name for Typhlocyba froggatti Baker.

In this thesis Froggatt's apple leafhopper (FALH) will be used as the common name.

2.2 Biology of *Typhlocyba froggatti* Baker.

A number of papers relating to the biology of FALH on apple have been published in Australia (Noble, 1929; Evans, 1935, 1940a; Ward, 1936, 1938; Jenkins, 1943) and New Zealand (Dumbleton, 1934, 1937) yet only two authors: Noble (1929) and Dumbleton (1934) studied the insect in depth.

(i) Origins and Distribution.

FALH was considered to be of European origin by Dumbleton (1934), Evans (1935) and Jenkins (1943). According to Dumbleton (1934) this leafhopper first came into prominence as a pest of apple in New Zealand about 1918. Evans (1935) suggested that the insect may have reached Australia from America. Presumably it reached America from Europe. One can only surmise, because of its early discovery in New Zealand, whether it arrived directly from Europe, or came via Australia and/or America.

In view of this insect's method of overwintering, Dumbleton (1934) suggested that it gained entry to New Zealand in the egg stage under the bark of imported trees, rootstocks or cuttings. FALH is considered to be generally distributed throughout apple growing areas of New Zealand (Cottier, 1956).

This leafhopper is now established in many apple growing countries of the world. Metcalf (1968) reported that it had been located in the following countries: France, Germany, Poland, Czechoslovakia, Switzerland, the Netherlands, Finland, Sweden, Great Britain, U.S.A, Canada, Argentina, Chile, Australia and New Zealand.

(ii) Life History (Apple).

The life cycle of FALH has been described by Dumbleton (1934) for Nelson, New Zealand and Noble (1929) for New South Wales, Australia.

This leafhopper overwinters in the egg stage in the fleshy tissues of the upper layers of the bark of twigs. The first generation eggs hatch in spring, about the last week of September at Nelson (Dumbleton, 1934), and proceed through five nymphal instars to first generation

adults. In Nelson there were very few insects still in the nymphal stage by the third week of December (Dumbleton, 1934). The adults of FALH feed for about a week before mating and then lay second generation eggs which are deposited in the midribs and veins of leaves. Second generation eggs were noticed by Dumbleton (1934) about the first week in December. After hatching, the second generation nymphs again proceed through five nymphal instars until they mature into second generation adults. There were very few first generation adults remaining as second generation nymphs neared maturity (Dumbleton, 1934).

Under most conditions the eggs of the second generation adults are deposited underneath the bark of twigs where they overwinter. Dumbleton's (1934) preliminary observations indicated that the species had two generations in Nelson. Two generations have also been observed by DeLong (1931) in Ohio, U.S.A; Chiswell (1964) in England; and Jenkins et al. (1950) in Western Australia. In warmer conditions it is likely that a third generation exists such as was reported by Noble (1929) for New South Wales and Kemp (1938) for South Australia.

Diapause has not been studied for this species, but is probably very similar to the eudiapause described by Muller (1979) which included all polyvoltine leafhoppers with egg diapauses whose dormancies had been sufficiently studied up until that time. Eudiapause would help explain the third generation exhibited by FALH in warmer conditions.

(iii) Habits.

All active stages were normally found sheltering on the underside of apple leaves by Noble (1929) and Ward (1936) and the nymphs, if found on the upper side invariably moved to the underside of the leaf when disturbed. Noble (1929) also noted that by far the greatest number of leafhoppers were present on the leaves of the lower half of the tree, particularly on short spurs in the vicinity of the main limbs and crown.

Evans (1940a) stated that during the whole of their growing period nymphs seldom wandered away from the leaves they first began feeding on, even when these leaves hardened and softer ones became available. Dumbleton (1937) indicated a preference of FALH nymphs for older leaves.

The adults when disturbed were observed to leap and fly into the air in an unsustained short flight outwards from the tree followed by a rapid return (Noble, 1929). Thus, according to that author, spread through an orchard may occur but at a slow rate from tree to tree. For this reason and because there were few alternative hosts available, Ward (1938) stated that rapid dispersal was uncommon. Ward (1938) suggested that isolated outbreaks of FALH populations would seem to be due to the presence of overwintering eggs brought into an orchard on nursery stock.

(iv) Hosts.

Several authors have reported FALH on a number of host plants belonging to the Rosaceae.

This species was frequently noticed by Noble (1929), in New South Wales, on pear and prune trees adjacent to apples. Prune also had visible signs of feeding and nymphs and adults fed freely on foliage of a climbing rose in the insectarium (Noble, 1929). Dumbleton (1934) reported that food plants of this insect included: Crataegus and plum in France; apple in the United States of America; and apple and hawthorn (Crataegus oxycantha) in New Zealand. In Victoria Australia, Ward (1936) made an examination of many potential alternate host plants of FALH but could not find the insect on any kinds of tree, other than apple, or on any species of weed. Contrary to Noble (1929), Ward (1936) stated that pear and plum trees adjoining heavily infested apple trees were not attacked. In South Australia, Kemp (1938) found FALH commonly on quince, plum, wild and cultivated hawthorn, rarely on pear, as well as on apple. The list of hosts was further increased by Jenkins (1943) who stated that the insect had been observed feeding on blackberry. Evans (1940a) stated that adults and nymphs were able to feed on a wide range of plants belonging to the Rosaceae, but in general only occurred in large numbers on apple trees and hawthorn

hedges. Evans also suggested that in seasons of exceptional abundance the insect will migrate to nearby cherry, plum, and pear trees, also to roses and to various kinds of ornamental Crataegus. In Great Britain Massee (1941) made every effort to ascertain the host plants that leafhoppers actually lived and fed on. For FALH that author included: apple, plum and quince as host plants.

The host range in relation to total life cycle is less defined in the literature. Noble (1929) found that apple was the only tree in which FALH deposited its eggs and Jenkins (1943) supported this statement by doubting whether breeding took place on any tree other than apple. However, work carried out by Dumbleton (1934) would strongly suggest that FALH could complete its life cycle on hawthorn. Evans (1940a) observed that populations of FALH were seldom able to maintain themselves in consecutive seasons on host plants other than apple and were never sufficiently numerous to be considered pests. Phillips (1950) stated that FALH was found breeding in small numbers on apple, plum, sweet and sour cherries and eastern choke cherry in Canada, but that author did not clearly indicate what was meant by 'breeding'.

2.3 Damage and Economic Importance.

(i) Damage.

Smith (1967) defined insect damage in five categories. At least three of these are exhibited by FALH, types 1, 4 and 5. Type 1 results in loss of productivity. The insects fed on plant parts so that the vigour, longevity or 'productive capacity' of the plant is reduced. The plant is not killed. Type 4, product contamination, occurs where the insects contaminate the marketed product. The contamination may affect the appearance and hence the marketable quality of the product but not the nutritional quality. Type 5 is the destruction of stored products.

A. Type 1.

Like most other members of the Typhlocybinae, FALH feeds in the palisade and spongy parenchyma of leaves, in contrast to other subfamilies of the Cicadellidae, which feed in the vascular tissues (Chiswell, 1964). This mesophyll habit has been described as the more specialised and may explain the lack of viral transmission among the Typhlocybinae (Putman, 1941).

The feeding of Typhlocyba pomaria McAtee, another mesophyll feeder considered to be very similar to FALH, has been described by Putman (1941). The feeding stylets punctured the cells of the palisade and spongy parenchyma and their contents were removed after cytolysis by the saliva. The saliva appeared to act only on the cells into which it was injected and did not diffuse through the tissues.

Leafhopper feeding is initially evident when each group of emptied cells becomes visible externally as a small whitish spot. Frequent feeding results in the characteristic finely speckled or stippled appearence of infested leaves (Chiswell, 1964). Large numbers of FALH on leaves caused them to turn yellow and in some cases of severe infestation to drop from the tree (Dumbleton, 1934). Extensive destruction of leaf cells impedes the normal function of the leaves and leads to a reduction in vigour. This may lead to induction of weak leaf and fruit buds and so adversely affect the fruit crop carried on the trees in the following season (Ward, 1938). Seedlings infested with large numbers of this insect early in the season can be damaged seriously if unprotected (Noble, 1929).

B. Type 4.

This type of damage results from excrement produced by all mobile stages of the insect. Both Noble (1929) and Evans (1935) considered this to be more serious than the damage mentioned previously.

Specks of excrement constitute a blemish on fruit destined for export markets (Dumbleton, 1934) and where found in large amounts will reduce the local market value of the fruit or render it totally unsaleable (Noble, 1929). Accumulated excrement on the fruit may be partly dissolved by rain, dew or spray material which produces dirty brown streaks and blots on the surface of the fruit (Ward, 1938). The

excrement cannot be removed easily and any attempt would increase the cost of preparing the fruit for market.

C. Type 5.

The excrement is reported to be a suitable medium for the growth of fungi which leads to decay of the fruit if kept in store (Dumbleton, 1934; Kemp, 1938). Thus the keeping quality of the fruit is impaired. Kemp (1938) found that this fungus became important long before there were sufficient leafhoppers to cause damage of significance by actual leaf destruction.

D. Economic Threshold Levels.

No economic threshold levels for this insect have been established. Counts of 31 nymphs per 100 leaves for the first generation and 56 nymphs per 100 leaves for the second generation were not sufficiently large to cause extensive damage either by destruction of leaf tissue or by speckling of the fruit (Dumbleton, 1937).

(ii) Economic Importance.

A. New Zealand.

FALH became noted as a pest of apple in New Zealand in about 1918 (Dumbleton, 1934). First reports of it in the literature suggest that it was a sizable problem (Anon, 1920; Hyde, 1920). Miller (1922) went so far as to list it as one of the more outstanding injurious insects which came under notice during the 1921-22 season. Its abundance in apple orchards was described as 'alarming' by Cockayne (1924), 'invoking a great need for investigational work regarding its successful control'.

Even though adequate controls appeared to have been established (Cockayne, 1926; Dumbleton, 1934), work on the study and importation of natural enemies was continued (Dumbleton, 1934, 1937). It seems that not until the advent of DDT to orchard spray programmes that this insect was relegated to minor pest status (Cottier, 1956). In general FALH has been adequately controlled by insecticides applied for the 'key pests' although occasional control measures aimed specifically at it may be needed (Collyer and van Geldermalsen, 1974).

B. Overseas.

DeLong (1926) reported an outbreak of FALH in central Ohio where, during the previous two seasons, the insects became so abundant in commercial orchards that excretra on the fruit caused a commercial loss due to the reduction in the market value of the apples. In Victoria, Australia, Ward (1936) reported a severe outbreak in the 1935-36 season. Insects were found over a wide area and by harvest extensive tree injury and fruit blemishing had been caused. The insect was regarded as of considerable economic importance. It is now likely, as the dearth of literature indicates, that FALH is considered a secondary pest in these areas, as it is in New Zealand. To the knowlege of this author FALH has never been recorded as a major pest in Europe.

2.4 Control.

Control of FALH in New Zealand is normally attributable to chemicals applied for the 'key pests': codling moth and leafroller. The egg parasite Anagrus armatus (Ashmead) occurs wherever leafhoppers become abundant but does not cause adequate mortality (Collyer and van Geldermalsen, 1976)

(i) Chemical Control.

The earliest reference to chemical control was given by Froggatt (1918) in the paper that first described this insect. Froggatt suggested that kerosine emulsion or tobacco and soap wash should be effective contact poisons for FALH in all stages of development. Nevertheless, the best time for control was suggested to be early summer before the first generations adults had had time to develop.

In New Zealand lime-sulphur sprays kept the pest well under control (Anon, 1920). Again early sprays were emphasised, aimed at the nymphal stage, as it was reasoned that the winged adult would be more difficult to control. Spray experiments carried out at Wakatu, N.Z, indicated that the insect could be kept under control if nicotine was included with an early calyx spray and followed by applications as found necessary (Hyde, 1920).

A number of control experiments were carried out by Noble (1929) in New South Wales. This author suggested the most effective control could be obtained by spraying, with nicotine sulphate, the underside of the leaves before the first generation nymphs reached the adult stage. Two sprays were necessary to secure adequate control. Dumbleton's (1934) recommendations were very similar to Noble's (1929). He suggested that the first spray of nicotine sulphate should be applied when the winged insects appear. The second spray, following three or four weeks after the first, was intended to kill any insects which hatched after the first spray became ineffective. If control in the second generation was needed, two sprays at the same phenological events were suggested. Similar recommendations were given by Evans (1935, 1940a) for Tasmania, Kemp (1938) for South Australia, Ward (1938) for Queensland and Jenkins (1943) for Western Australia. Several authors suggested that the first leafhopper spray could be combined with sprays aimed at codling moth (Ward, 1938; Evans, 1940a; Anon, 1940; Jenkins, 1943).

Overwintering eggs are well protected by the bark against chemical control.

With the introduction of DDT and DDD for the control of orchard pests after the Second World War, it soon became clear that these chemicals were more effective against FALH than those used previously (Jenkins and Forte, 1946; Miller, 1949; Jenkins et al., 1950). In New Zealand DDT was introduced into orchard spray programmes about 1948 (Anon, 1948; Taylor, 1948), and was recommended by Cottier (1956) as giving best control when applied before the adults had had time to develop.

The use of broad spectrum insecticides, such as DDT and DDD, in apple orchards relegated FALH to a minor position in pest status. The introduction of organophosphate insecticides, with the advent of resistance of some insects to organochlorine insecticides (Collyer and van Geldermalsen, 1976), and problems associated with toxic residues (Valentine, 1964) have made no difference to the pest status of FALH. Control by azinphosmethyl was as good as DDT/DDD for leafhopper in experiments at Havelock North reported by Harrow (1959).

A. Resistance.

Although resistance has not been established experimentally for FALH it was reported that it appeared to have developed to DDD/DDT in some New Zealand orchards (Anon, 1964). MacKenzie (pers. comm.) stated that as far back as 1962 there was visual evidence of leafhopper control being inadequate in some orchards in the Nelson area under a regular DDD and DDT spray schedule. Soon afterwards growers changed to azinphosmethyl (Gusathion) and the leafhopper problem disappeared.

A closely related leafhopper, Typhlocyba pomaria, has developed resistance to insecticides in the United States. T. pomaria has a similar life cycle, similar host plants and similar habits to FALH. It developed resistance in the late 1950's to DDT and again in the late 1960's when serious outbreaks occurred under the organophosphate insecticide, azinphosmethyl (Trammel, 1974). Although FALH has occurred in abundance in orchards of eastern North America (Delong, 1931) there are few references to its response to chemical control there. Phillips (1950) found interest in the extent to which FALH was replacing T. pomaria in Ontario, and whether greater resistance to DDT was causing an increase in the former species. However, that author gave no further insight into the problem.

No information could be found on the resistance of FALH to organphosphates.

(ii) Biological Control.

A. Parasites.

Dumbleton (1934), at the Cawthron Institute New Zealand, discovered that overwintering and summer eggs of FALH were parasitised by a mymarid wasp (Anagrus armatus (Ashmead)). That author gave some detail of the parasite's development, morphology, biology and efficacy as a parasite.

Examination of overwintering eggs of FALH taken from Auckland, Hastings, Blenheim and Dunedin revealed the presence of the parasite in all these districts (Dumbleton, 1934). In a later paper, Dumbleton (1937) established further data on parasitism by A. armatus. These two

papers indicated that winter eggs of FALH were parasitised between 78 and 93% while summer eggs were parasitised at 66%. This amount of parasitism represented a significant control factor in the regulation of FALH populations although, as both Cottier (1956) and Collyer and van Geldermalsen (1976) stated, they do not give adequate mortality to prevent leafhopper damage.

Dumbleton (1937) related the introduction, from New York into the Nelson district, of a dryinid parasite of the mobile stages of T. pomaria, Aphelopus typhlocybae Muesbeck. In this paper Dumbleton included the collection, shipment, treatment and liberation of the parasite and observations on its development and efficacy on FALH. Dumbleton (1937) proved that the Aphelopus larva was able to complete its development in FALH and considered that this parasite promised to establish successfully.

No further references to parasites of FALH were found. However there is some literature on the parasitism of leafhoppers related to FALH. Dumbleton (1934) summarised this up until 1934. Since that time Armstrong (1935), Mulla (1956), Seyedoleslami (1978) and Seyedoleslami and Croft (1980) have investigated parasites of Typhlocyba sp. on apple and Jervis (1980) has discussed the life history of the primary parasites of typhlocybine leafhoppers.

B. Predators.

Records on the predators of FALH are scarce. Dumbleton (1938) suggested that a mirid (Idatiella albisigata Knight) possibly fed on the eggs of FALH but gave no evidence to verify it. Crabro davidsoni Sandh, a sphecid wasp, was apparently a predator of several leafhoppers including FALH. One FALH adult was identified from cells of C. davidsoni galleries (Davidson and Landis, 1938). These few references on predators may indicate their lack of importance in FALH control.

For other Typhlocyba spp., reviews of predators have been made by Dumbleton (1934) and Seyedoleslami (1978).

(iii) Natural Control.

There is little reference to the influence of climate on this leafhopper. However Dumbleton (1934) reported that damage to leaves and blemishing of the apples were more pronounced in years of high temperature and low rainfall during the period January to April.

(iv) Cultural Control.

It does not appear that the use of cultural methods for control have been implemented against FALH. Nevertheless, a few suggestions have been made.

According to Noble (1929) the overwintering eggs are deposited most extensively in bark of wood which has developed during that season, therefore the removal of the current season's growth during the normal pruning operations will result in the destruction of a large number of eggs. In view of the number of Anagrus parasites that would also be destroyed with the prunings, Dumbleton (1934) suggested that it may be advantageous to devise a method of disposing of prunings which allowed the parasites to complete their development and emerge from the twigs.

Late varieties of apple were reported to be more likely damaged due to the buildup of leafhopper populations over the season (Ward, 1938; Jenkins, 1943).

CHAPTER III.

SAMPLING CONSIDERATIONS.

3.1 Description of Study Areas.

Sampling was carried out in three orchards in the vicinity of Christchurch, New Zealand. A summary of the methods used in the sampling programme is given in Table 3.1.

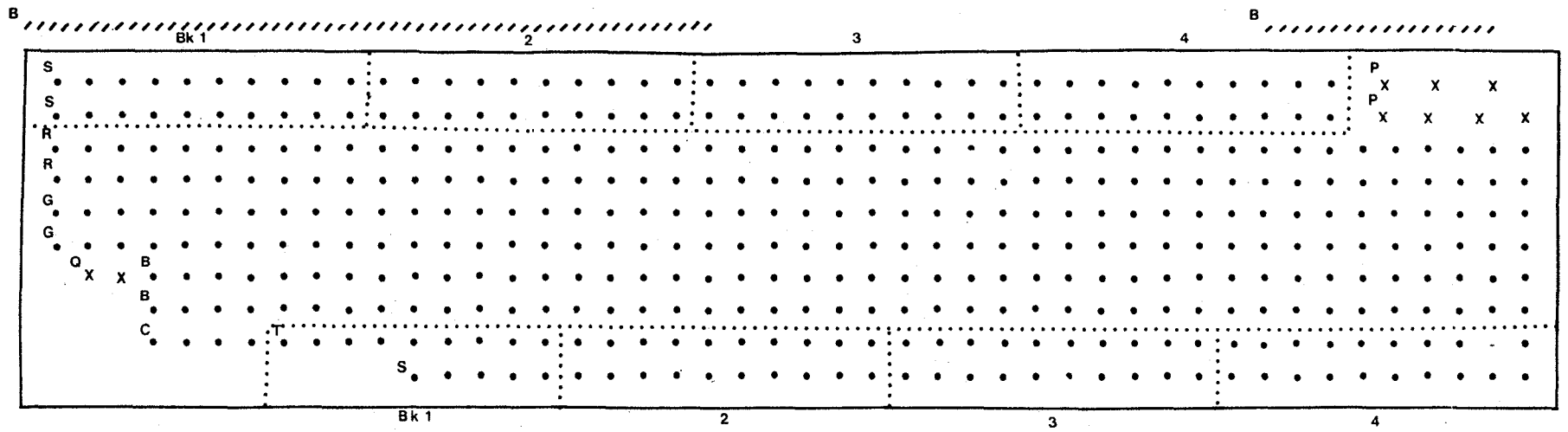
Table 3.1: Outline of sampling in the three orchards:

	Orchard 1.	Orchard 2.	Orchard 3.
Sleeve cages	A.armatus.(2) FALH nymphs.(2) FALH adults.(2)		
Sticky traps	A.armatus.(1,2) FALH adults.(1,2)	FALH adults.(1)	FALH adults.(1,2) A.armatus.(1,2)
Leaf samples	FALH nymphs.(1,2) FALH eggs. (1,2)		
Branch samples	FALH eggs.(1981)		

(1) 1980-81 season.
(2) 1981-82 season.

Orchard 1. Abandoned Orchard (see Figure 3.1). This orchard was characterised by extremely unkempt trees, originally pruned to the 'vase system' that were overgrown and larger than trees usually found in well managed orchards. Almost every tree was ring-barked below 0.75 m by feeding sheep. Furthermore, lack of irrigation added to the stress placed on the trees and combined with silverleaf (Stereum purpureum) it was not uncommon for a tree to suffer premature leaf fall. In the sampling programme, when a tree became unhealthy to the extent that a large proportion of its foliage was affected, another tree was randomly selected to replace it. Before the start of the

FIGURE 3.1: Orchard 1 (Abandoned Orchard).



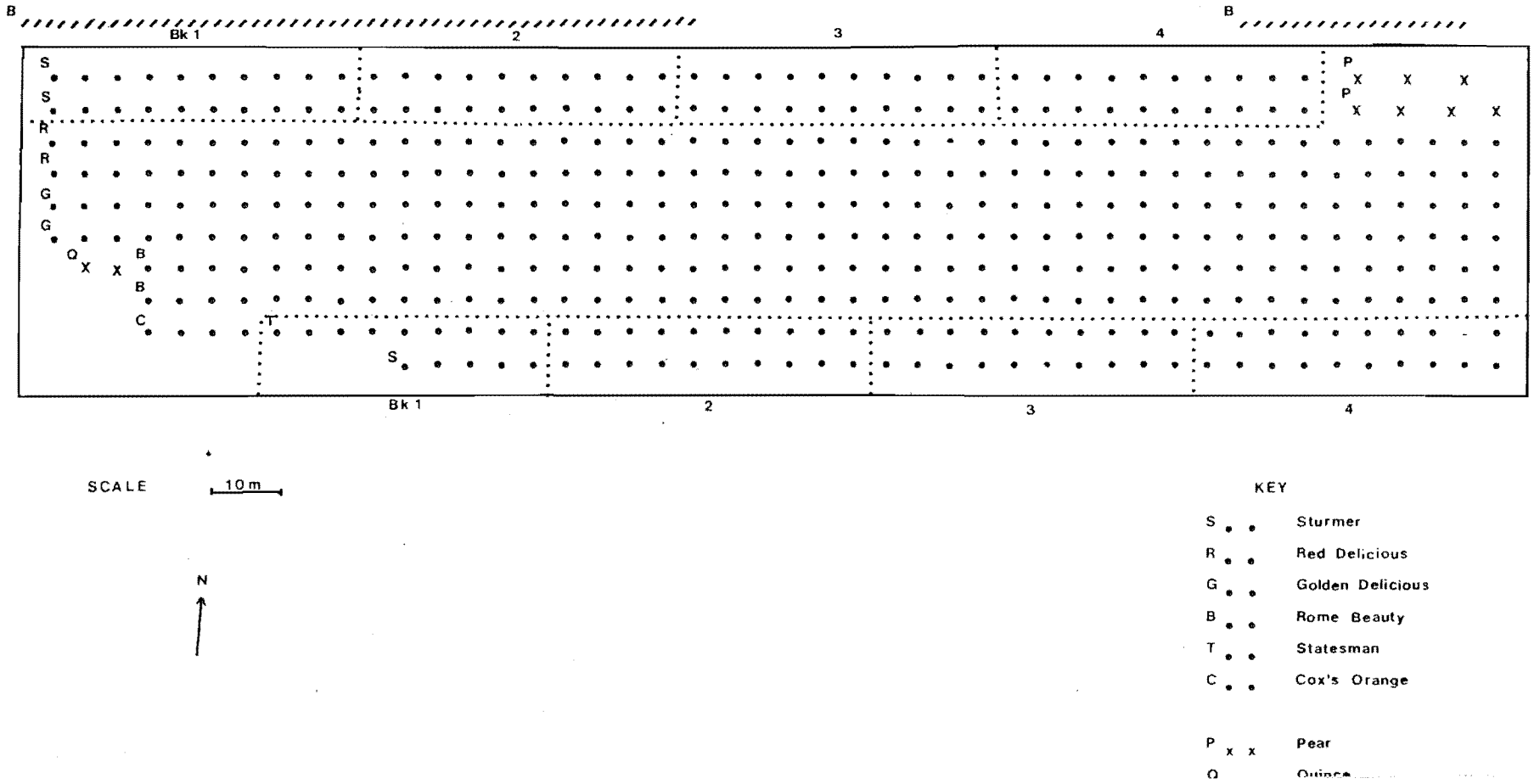
second season a large number of the trees at the western end of the orchard were removed.

The two rows on each outer side, only, were sampled as it was considered that the rest of the orchard was too dissimilar from managed situations. These middle trees were overgrown to the extent that their branches were difficult to distinguish from neighbouring trees. The conclusions about leafhoppers in Orchard 1 were thus deficient, as they were based on trees that were suscetable to boundary effects. Nevertheless, the conclusions were thought to be better than those established from the inner trees or none at all. Each side of the orchard was characterised by trees of different morphology; the northern side had larger trees (up to 5 m), with greater growth within the crown than the southern side (up to 4 m). This made sampling more difficult as allowance had to be made for the different tree types on either side. The ground cover included many different weed species (see Appendix 1) and was left uncut throughout the two seasons studied. Blackberry was not found within the orchard although it was very common on the northern border outside the tall poplar shelter and sporadically on the southern border amongst the tall poplar shelter. The shelter at the eastern and western boundaries was Douglas fir (Pseudotsuga menziesii). The soil consisted of Kaiapoi silt loam which usually indicates imperfect to moderate drainage. The surrounding area was mainly pastoral with some residential land. A drainage ditch ran down the northern boundary outside the poplar shelter. No insecticide applications had been made for at least 5 seasons and there were none during the study. One fungicide application (for powdery mildew) occurred in November 1981 on trees of the southern two rows only.

This orchard was intensively sampled to determine the temporal and spatial distribution of FALH in an unmanaged situation.

Orchard 2. Unsprayed Orchard (see Figure 3.2). This was a research orchard at Lincoln College. The trees were well managed and well irrigated and in a state of comparative good health. Size of the trees ranged between 1.5 and 3 m and were pruned to the 'centre leader system'. Ground cover was cut occasionally and consisted of a strip of ryegrass and clover, with a few weeds (see Appendix 1), between bare earth under the trees. Blackberry plants were found in small numbers

FIGURE 3.1: Orchard 1 (Abandoned Orchard).



inside the orchard. Shelter consisted of poplars encompassing the whole orchard and surrounding land use included: mixed cropping, pasture, and intensive horticulture. The soil, Wakanui silt loam, is imperfectly drained but has a moderately high to high natural productivity.

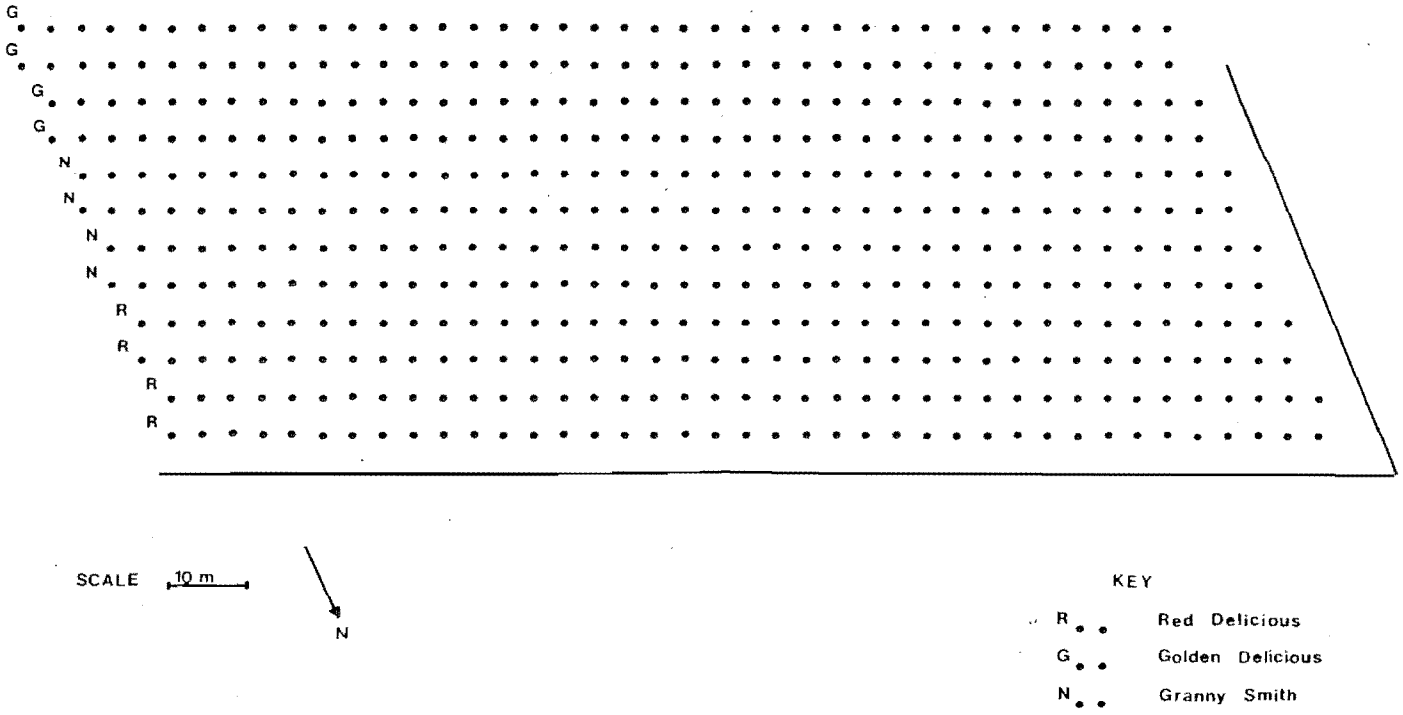
Sampling of this orchard was carried out only during the 1980-81 season when there were no insecticide applications and only one miticide application of cyhexatin (60 gm AI/100 litres) on 12 November. The previous season's spray programme included a number of insecticide and miticide applications throughout the whole season.

This orchard was sampled to establish the ability of FALH to re-invade an uncontrolled environment.

Orchard 3. Commercial Orchard (see Figure 3.3). The trees in this orchard were slightly overgrown but were otherwise healthy, between 2 and 3 m in height and pruned to the 'centre leader system'. The orchard received calendar insecticide and fungicide applications. It was well irrigated. Ground cover consisted of ryegrass-clover in the 1980-81 season. Early in the 1981-82 season the ground cover was removed by herbicides and until weeds started to regrow at the end of the season the ground was bare except for a few blackberry plants. The 'Golden Delicious' trees were removed before the beginning of the 1981-82 season. Along the northern boundary, blackberry was very common in the 1980-81 season, but this was mostly removed early in the 1981-82 season. Poplar shelter occurred to the north, west and east and the surrounding countryside was predominantly made up of orchards with some pastoral land. Two soil types occurred in this area: Taitapu silt loam which is subject to seasonally high water tables but in most places drainage is now adequate, and Waimakariri fine sandy loam which is potentially productive; it retains moisture well but is still free draining.

This orchard was sampled to determine the extent of FALH infestation in a commercial orchard.

FIGURE 3.3: Orchard 3 (Commercial Orchard).



3.2 Dispersion and Transformation.

(i) Dispersion.

The description of the pattern of distribution or disposition of animals in space is termed 'dispersion' and is of considerable ecological significance. An understanding of dispersion is important to the sampling programme, data analysis, the analysis of density changes, and of predator/prey and parasite/host interactions (Southwood, 1978). Brown and Cameron (1982) emphasised this by stating:

> The spatial distribution of individuals within a population is an attribute of the population that must be known before we can either understand its dynamics or attempt any management of the population. Patterns of dispersion can have profound effects on the interaction among species (Hassell and May, 1974) and among individuals within a species (Taylor and Taylor, 1977). Population dispersion is not static; rather, it is continually changing in response to the recent history of both the population and the environment (Poole 1974). Because of this dependence, investigation into the dynamics of a population's dispersion can provide insight into the processes influencing the dynamics of the population as demonstrated by Waters and Hensen (1959) and Harcourt (1961) concerning the spatial and temporal changes in populations of several insect species.

A number of measurements of dispersion have been derived and these have most recently been reviewed by Southwood (1978). Among the most common models involved in the measurement of insect dispersion has been the negative binomial (Taylor, 1961; Southwood, 1978). This distribution is described by two parameters: the mean and the exponent k. The indice k is a measure of the amount of clumping and is often referred to as the 'dispersion parameter'. For some time limitations of k of the negative binomial have been known (Anscombe, 1949; Taylor, 1961) but it has continued to be the most commonly used approach to describe dispersion. Recently criticism has increased, centering on

the instability of k as the population density changes. According to Taylor (1971) if aggregation is to be defined quantitatively the definition must: 1) indicate the range of individual behaviour as simply as possible; 2) simultaneously relate to all population levels; 3) apply to all species. A spatial pattern which, for quadrats of a fixed size, gives rise to the negative binomial will not necessarily do so when the quadrat size is changed. In fact there is no spatial pattern that can be characterised by a negative binomial, apart from a special case where the clusters are so compact that whenever one member of the cluster falls in the quadrat so will all the others (Paloheimo and Vukov, 1976). Myers (1978) found that all measures of aggregation associated with k of the negative binomial were relatively strongly correlated to density. The interpretation of k thus remained suspect and the negative binomial could not be regarded as having any biological significance over a range of densities (Taylor et al., 1978). Taylor et al. (1979) further criticised the use of k as an index for aggregation. Myers (1978) recommended the use of three indices for biological studies in which the relationship between density and dispersion of organisms may be changing at the same time, namely: Green's coefficient of dispersion (Green, 1966), the standardised Morisita's coefficient of dispersion (Smith-Gill, 1975) and the mean/variance ratio. The indices proposed by Green (1966) and Smith-Gill (1975) have, however, been frequently overlooked by biologists (Myers, 1978). Myers also pointed out that the mean crowding index (Lloyd, 1967) is not useful unless related to the mean density as suggested by Iwao and Kuno (1971).

Taylor's Power Law. If the mean and variance of a series of samples are plotted they tend to increase together. This relationship has been shown by Taylor (1961, 1965, 1971) to obey a power law which holds in a continuous series of distributions from regular through random to highly aggregated.

The relationship is expressed by:

$$(1) \qquad s^2 = a\,\bar{x}^{\,b}$$

where a and b are constants, a being largely a sampling factor, while b is an index of aggregation characteristic of the species. The series of means and variances necessary to calculate b may be obtained from

several sets of samples from different areas, from sets of samples of different sizes or by combining samples to form different sized sampling units (Southwood, 1978). The index of aggregation, b, is calculated as the slope of the regression between $\log(s^2)$ and $\log(\bar{x})$, i.e. from the equation:

$$\log(s^2) = \log(a) + b \log(\bar{x}) \qquad (2)$$

The exponent b can vary from negative to positive. Large values of b indicate increasing aggregation; values of b greater than 1 indicate a contagious distribution while uniform or equally spaced distributions have values of b less than 1. The random or Poisson distribution occurs when a=b=1. This index of aggregation incorporates the density dependence of aggregative behaviour and is thus free from the conpounding effects of density (Taylor et al., 1978). Downing (1979) listed other advantages of Taylor's power function as: its applicability over a range of sample sizes; its ablility to be calculated if only some measure of dispersal is given with population data; that it can describe many types of distributions in one mathematical expression.

Iwao's Patchiness Regression. Iwao (1968) suggested an alternative approach to the analysis of spatial distribution and showed that Lloyd's (1967) 'mean crowding' index ($\overset{*}{m}$) was linearly related to mean density:

$$\overset{*}{m} = \alpha + \beta m \qquad (3)$$

where $\overset{*}{m}$ is calculated from:

$$\overset{*}{m} = m + [(s^2/m) - 1] \qquad (4)$$

The constant α indicates the tendency to crowding (+ve) or repulsion (-ve) and is known as the 'Index of Basic Contagion' (Southwood, 1978). This indicates whether the basic component of the distribution is a single individual ($\alpha = 0$) or a cohesive group of individuals. The coefficient β is related to the pattern in which the organism utilises its habitat and is known as the 'Density Contagiousness Coefficient'. Coefficient β expresses the extent to which the colonies (as defined by α) are contagious at higher densities. For randomly distributed

colonies $\beta = 1$ and for aggregated distribution of colonies β is greater than 1. Iwao's method is simple and like Taylor's power law describes many types of distributions in one mathematical expression. It has been widely used to investigate spatial pattern (East, 1980).

Iwao and Kuno (1971) criticised Taylor's power law as being invalid from both theoretical and biological viewpoints, and that it was only useful as an empirical, approximate method. In theory Taylor's method is not compatible with that of Iwao's except where $\alpha = -1$ or $\beta = 1$ (Iwao and Kuno, 1971). Nevertheless Taylor's power law has remained a simple and useful description of species distribution (Southwood, 1978). Taylor *et al.* (1978) showed that the power law was generally superior to Iwao's model, for detecting and summarising changes in spatial distribution for a wide range of organisms over a wide range of densities.

Therefore, due to the present uncertainty in the description of distribution, both the approaches of Taylor and Iwao are used in this thesis. This procedure has been followed by several authors recently (East, 1980; King *et al.*, 1981; Bechinski and Pedigo, 1981). Any expression of dispersion involving k of the negative binomial was avoided due to its apparent inconsistency.

(ii) Transformation.

In order that parametric statistical methods may be applied to raw data, the assumptions of normal analysis of variance must be satisfied. These include that the data is normally distributed, the variance is independent of the mean and its components are additive (Southwood, 1978). To satisfy these conditions the raw data must be transformed. Hayman and Lowe (1961) pointed out that as non-normality must be extreme to invalidate the analysis of variance it is better to concentrate on stabilizing the variance of the samples. A correct transformation for this property will also satisfy the additivity of variance (Bliss and Owen, 1958).

Taylor (1961) showed that an exact transformation can be calculated if the power relationship of the variance to the mean is known.

The variance can be stabilised by transforming the original data using the equation:

$$z = x^{p} \qquad (5)$$

where x = the original (raw) number, z = the transformed value and p = 1 -0.5(b), where b is the exponent formed in equation (2). If p = 0 a logarithmic transformation should be used, p = 0.5 square roots, p = -0.5 reciprocal square roots, and p = -1.0 reciprocals. (Southwood, 1978). Healy and Taylor (1962) gave tables for p = 0.2, 0.4, 0.6, 0.8 and for the negative powers.

Iwao and Kuno (1971) concluded that it may have been safe to rely on four formulae to transform a wide range of biological data so that the variance may be stabilised.
These were:

$$f(x) = \sin^{-1}\left(\frac{1-\beta}{\alpha+1}x\right)^{0.5} \qquad \text{for } \alpha > -1,\ \beta < 1 \qquad (6)$$

$$f(x) = (x)^{0.5} \qquad \text{for } \alpha > -1,\ \beta = 1 \qquad (7)$$

$$f(x) = \log(x) \qquad \text{for } \alpha = -1,\ \beta > 1 \qquad (8)$$

$$f(x) = \sin h^{-1}\left(\frac{\beta-1}{\alpha+1}x\right)^{0.5} \qquad \text{for } \alpha > -1,\ \beta > 1 \qquad (9)$$

According to Southwood (1978) it is often only necessary to carry out rough transformations as sampling and other errors are fairly large. That author stated that it is usually adequate to transform the data from a regular population using squares, from a slightly contagious one by using square roots and from distinctly aggregated or contagious populations by using logarithms. To overcome zero counts in log transformations it is necessary to add one to counts (Morris, 1955).

CHAPTER IV.

SAMPLING THE IMMATURE STAGES OF FALH.

4.1 Branch Sampling Directed at Overwintering Eggs.

(i) Introduction.

Overwintering eggs of FALH were deposited singly underneath the bark of twigs in a position more or less transverse to the length of the stem. Their presence was usually visible as a swelling in the bark of approximately 1 mm in length (Noble, 1929). The eggs themselves were reported to be approximately 0.6 mm long, elongate with rounded ends and of a general translucent white colour (Noble, 1929). A number of authors including: Noble (1929), Ward (1936, 1938), Kemp (1938), Evans (1940a, 1940b), Jenkins (1943) and Jenkins *et al.* (1950), all suggested that the eggs were laid predominantly in the young wood of the current season's growth. Only Evans (1940a, 1940b) gave circumstantial evidence for this phenomenon.

The number of overwintering eggs present in the twigs was established for a number of different apple varieties by Dumbleton (1934) but this work did not investigate the influence of branch age or express the results in terms of surface area. Dumbleton (1934, 1937) found an average of between 2.1 and 6.1 eggs per inch (0.53 and 1.55 eggs per mm) for a number of apple varieties.

The overwintering eggs of FALH are parasitised by a partially grown larva of the mymarid wasp, *Anagrus armatus* (Dumbleton, 1934). Dumbleton (1934, 1937) established parasitism rates of between 78 and 93% of overwintering eggs in various parts of New Zealand.

Apart from Dumbleton (1934, 1937) there is no literature regarding the sampling of FALH eggs and its parasite *A. armatus*. Armstrong (1935), investigating the parasitism of *T. pomaria* overwintering eggs by *Anagrus armatus* var *nigriventris*, caged four twigs and recorded the nymphs and parasites that emerged to determine the extent of parasitism. Armstrong also dissected overwintering leafhopper eggs to

determine the extent of parasitism by A. armatus. In neither of these samples was any allowance made for branch age or position in the tree. When investigating the spatial distribution of overwintering eggs of I. pomaria and its egg parasite Anagrus epos, Seyedoleslami and Croft (1980) randomly collected twigs from within the cardinal direction quadrats (i.e north, south, east and west) and levels of apple trees. Subsamples of a standardised 50 mm section of wood were examined for each annual growth age class. These authors found a close correlation between oviposition preference relative to distance from the branch terminal apex and the branch age classes, and therefore subsequently divided branches of 750 mm into 150 mm sections, randomly selecting 2 non-overlapping 25 cm bark sections as a subsample.

The primary aim of this investigation was to gain information on the distribution of overwintering FALH eggs within the tree with reference to height, aspect and age of wood, and secondly to gain some idea of the importance of parasitism by A. armatus on the overwintering FALH eggs.

(ii) Materials and Methods.

Sampling of overwintering eggs was carried out only in the abandoned orchard, Orchard 1 (see Table 3.1). Preliminary investigation showed that there were very few eggs in the unsprayed orchard (Orchard 2) and because there were even fewer leafhoppers in the commercial orchard (Orchard 3) it was thought that meaningful data would only be gained from the abandoned orchard.

Sampling of all schedules was carried out between 15 September and 19 September 1981. In all the schedules if a tree chosen was known to be unhealthy another tree was randomly selected to replace it.

Schedule 1. Six trees were randomly selected from the two northern 'Sturmer' rows (see Figure 3.1). It was found that the lower branches of the trees, adequately represented only about two of the previous five · year's growth. As the aim of the investigation was to examine as many branch ages as possible only branches above 2 m were sampled. The upper level was divided into the four cardinal directional quadrats (i.e. N, W, S, and E) and a suitable branch

exhibiting four bud scars was selected and removed from the tree. In the laboratory a 50 mm representative of each year's growth, up until the fifth year, was randomly selected from each branch. Each 50 mm subsample was then examined under a binocular microscope to determine the number of FALH eggs present. This was accomplished by dissecting the swellings on the bark for living material. At the same time egg parasitism was ascertained. A parasitised egg was readily identified by the whitish streak of fatty tissue present within the body of the partially grown parasite (Armstrong, 1935).

The bark surface area was determined, assuming that the 50 mm subsample represented a cylinder, and the number of eggs present were expressed as numbers per unit surface area.

Sampling from schedule 1 indicated little difference in egg numbers on different aged wood (see results). Therefore the subsequent sampling schedules were established assuming that there was no difference in egg numbers on varying aged wood over the whole tree .

Schedule 2. Six trees were randomly selected from the two northern 'Sturmer' rows. Each tree was divided into two levels: below 2 m (L) and above 2 m (U), and each level was then subdivided into the four cardinal directional quadrats (N, W, S and E). In each quadrat a branch was chosen and removed that had growth from either the previous second or third season represented. In the laboratory a 50 mm long strip of wood was randomly selected from either the previous second or third season's growth. Each subsample was then examined for eggs and parasitised eggs in the same manner as in schedule 1 and their numbers expressed in terms of surface area.

Schedule 3. Five trees were randomly selected from the one southern 'Sturmer' row (see Figure 3.1). The sampling schedule was otherwise identical to schedule 2.

Data analysis. The means and variances of the treatments from all the sampling schedules were used to establish the respective indices of Taylor's power law and Iwao's patchiness regression. The data were transformed as indicated by Taylor's power law and Iwao's patchiness regression and tested for stability of the variance by calculating the correlation coefficient for the variance and mean (Harcourt, 1961).

Any significant statistical differences of egg counts in relation to age, height and quadrat were examined by ANOVA. No analysis of the parasitised egg counts was undertaken, for reasons that will be given later.

(iii) Results and Discussion.

Analysis of Variance. Taylor's power law and Iwao's patchiness regression (see Tables 4.1 and 4.2) both indicated that a square root transformation was appropriate for the egg count data. This is consistent with the transformation of small whole numbers suggested by Steel and Torrie (1980). Table 4.3 indicates that this transformation stabilises the variance for all three sampling schedules. The analysis of variance (see Table 4.4) indicates that there was no difference in egg distribution in relation to branch age (schedule 1), quadrat (schedules 1, 2 and 3) and height (schedules 2 and 3). In the population sampled the greatest variation in the transformed egg counts was between trees, where in schedule 3 this was significant ($p < 0.01$). These results give only a preliminary indication of the distribution of FALH overwintering eggs within the tree canopy due to small sample size. The limitation of time restrained a fuller investigation of this area. The apparent lack of preference for any age of wood is in contrast to the comments of many authors who have suggested that the eggs are laid predominantly in the young wood of the current season's growth. Nevertheless, they gave little evidence to support this assumption and the results of this study suggest otherwise.

Dispersion. Both Taylor's b and Iwao's β had values equivalent to unity for total egg counts indicating a random population distribution (see Tables 4.1 and 4.2). The intercept of regression of m^* on m was significantly greater than zero ($p < 0.001$) indicating that the basic component of overwintering egg distribution was a cohesive group of individuals. This type of distribution is the first described by Iwao and Kuno (1971) who suggested that this may indicate a Poisson distribution of colonies or clumps whose mean size remains approximately constant over a range of different densities. It is conceivable, in the case of FALH, that this distribution was the result

Table 4.1: Result of Taylor's power law for overwintering egg counts for the 3 schedules combined in Orchard 1, 1981.

n	log a ±S.E.	slope b ±S.E.	r^2
36	0.355 ±0.286	0.874 ±0.122	60.2

Table 4.2: Result of Iwao's patchiness regression for overwintering egg counts for the 3 sampling schedules combined in Orchard 1, 1981.

n	intercept α ±S.E.	slope β ±S.E.	r^2
36	0.251 ±0.135	0.989 ±0.011	99.6

Table 4.3: Correlation coefficient (r) for the mean and variance of overwintering egg counts of raw and transformed (square root) data.

	Raw data	Transformed data
Schedule 1.	0.785	-0.0866
Schedule 2.	0.786	0.175
Schedule 3.	0.83	0.181

Table 4.4: Analysis of variance on transformed overwintering egg counts for all schedules on apple tree branches, 1981.

	Schedule 1.		Schedule 2.		Schedule 3.	
Source of variance	df	F	df	F	df	F
Between trees						
Trees(T)	5	1.55	5	0.928	4	2.277 *[1]
Within trees						
Height(H)	NA	NA	1	0.227	1	1.391
Quadrat(Q)	3	1.514	3	0.65	3	1.613
Age(A)	4	0.856	NA	NA	NA	NA
Q x A	12	1.243	NA	NA	NA	NA
H x Q	NA	NA	3	0.185	3	0.644
Residual	94	-	35	-	28	-
Total	118	-	47	-	39	-

[1] $p < 0.01$

(for tabulated means see appendix 2)

of random visits to individual positions on apple tree branches by female leafhoppers who tended to lay more than one egg per visit.

Parasitism. Parasitism of overwintering eggs by A. armatus in the sample trees averaged 44.8, 31.9 and 53.3% in schedules 1, 2 and 3 respectively. This was much lower than that measured by Dumbleton (1934, 1937) and may be explained by lack of knowledge of the life cycle of this mymarid. In this study only one stage of the parasite's life cycle was sampled, i.e. the stage that had become obvious by the whitish streak of fatty tissue present, when it was likely that other life stages of the parasite were present but in other forms. Thus, the percentage parasitism measured in this study can only be regarded as a minimum. For this reason, it was decided that any attempt at analysis of variance and description of dispersion of the parasitised eggs might be misleading. Furthermore, unsuccessful attempts to transform the parasite data indicated the need of further data for accurate analysis.

(iv) Summary.

Overwintering eggs of FALH were described as randomly dispersed cohesive groups of individuals by the indices of Taylor's power law and Iwao's patchiness regression. There appeared to be no preference for egg oviposition in relation to branch age, quadrat (tree aspect) and height in the trees sampled. Conservative estimates of overwintering egg parasitism by A. armatus ranged between 30 and 53%.

4.2 Leaf Sampling Directed at Summer Eggs.

(i) Introduction.

Southwood (1978) suggested that in many ways plants are the most difficult habitat from which to sample insects. This is especially true when the insect life stage is embedded in plant tissue. It is possibly the main reason why the few authors who have studied FALH have paid any attention to the summer eggs which are deposited in the petioles, midribs and main veins of apple leaves (Noble, 1929;

Dumbleton, 1934; Ward, 1938; Jenkins, 1943). Dumbleton (1937) dissected 29 leaves from all parts of one 'Delicious' tree. He found an average of 1.1 eggs per leaf varying from 0 to 5, and of these, 66% were parasitised by A. armatus. Curtis (1942) proposed a method of bleaching and staining to detect the eggs of various Hemiptera in potato leaves under transmitted light. This method involved a number of separate steps and Carlson and Hibbs (1962) found that the same eggs could be counted after merely boiling for one minute in lactophenol, whereupon the leaf tissues became bleached and the egg proteins coagulated. A technique for staining and counting leafhopper eggs involving numerous steps and materials was described by Chatterjee and Ram (1970). Seyedoleslami, in his 1978 thesis (which was not initially available to this author) bleached apple leaves in 75% alcohol for 24 hours, then washed them and placed them in a petri dish of water. After this the eggs of T. pomaria could easily be counted under a binocular microscope. This method, however, proved inefficient in detecting newly oviposited transparent eggs and those on the surface of the leaves in the midrib area. Seyedoleslami observed that leaves kept at 40° F (4.4° C) for two weeks could be more easily dissected than when fresh. The effect of storage could be enhanced by keeping leaves at -5° C for one hour. When beginning to thaw, leaves treated in this way could be dissected and the eggs detected (Seyedoleslami, 1978).

The aim of this study was to gain information on the spatial and temporal distribution of FALH summer eggs and to investigate the importance of parasitism by A. armatus.

(ii) Materials and Methods.

Sampling of summer eggs was carried out only in Orchard 1, and apart from two occasions in the 1980-81 season was restricted to the two 'Sturmer' rows on the northern side.

First Season: 1980-81. The northern side of Orchard 1 was divided into 4 equal blocks of approximately 20 trees (see Figure 3.1), and from each of these one tree was randomly selected. Each tree was divided following the outline given by LeRoux and Remier (1959). This consisted of two levels; below 2 m (L) and above 2 m (U), which were further subdivided into the four cardinal direction quadrats (i.e. N,

S, E and W). In each quadrat 5 leaves were randomly collected, placed in a paper bag and taken back to the laboratory. The paper bags were placed in a sealed plastic bag in a refrigerator at 4° C until the leaves were analysed. For the purposes of this study, dissection was considered to be too time consuming and tedious and so the most simple method of leaf preparation for egg counting was undertaken. In the laboratory each sample of 5 leaves was boiled separately in lactophenol (see Appendix 3 for constituents) in a 250 ml Pyrex beaker for approximately 3 to 4 minutes, submerged with the aid of a wire mesh weight. Single leaves were then examined under a binocular microscope (x12.5) for the presence of leafhopper eggs in the midribs and veins and the number recorded for each leaf. Sampling of apple leaves for FALH eggs was initiated on 10 November 1980 and continued at approximately 7 day intervals until 28 May 1981. On 7 January and 8 April 1981 the south side of Orchard 1 was also sampled for FALH summer eggs. The two southern rows were divided into three blocks of approximately 20 trees and a fourth of 14 (see Figure 3.1). From each block one tree was randomly selected and thereafter the sampling procedure was similar to the egg samples of the northern side. In all there were 29 samples on 27 sampling dates.

At the begining of March it was observed that some FALH eggs took on a distinct red colour. This was later thought to show good evidence for the presence of parasitism by A. armatus (see results 1981-82) and therefore after 11 March 1981 the number of red eggs was also recorded.

Second Season: 1981-82. Four trees were randomly selected from the outer 'Sturmer' row, in the area encompassed by blocks 3 and 4 on the northern side of Orchard 1. Each tree was divided into two levels as in the previous season but not into quadrats. To select a sampling direction a small stick was spun quickly in a horizontal manner which when stopped, a predetermined end pointed to the sampling direction. Once the direction of sampling was determined, 5 leaves from the outer (O) and 5 leaves from the inner (I) canopy were collected at both levels and placed in groups of five in a paper bag for removal to the laboratory. For each tree this procedure was carried out twice. The paper bags were again placed in a sealed plastic bag in a refrigerator at 4° C until the leaves were analysed. In the previous season the leaf clearing procedure proved to be time-consuming, unhealthy and of

uncertain accuracy (see results 1980-81), and therefore another method was contrived for the 1981-82 season. The number of leaves of one sample (80) was divided and each half wrapped in a long terylene strip of fine mesh so that each sample of five leaves was separated. Both bundles were then placed together in acetone for approximately 25 minutes to help break down the surface waxes on the leaves. After draining and rinsing in cold tap water, the two bundles were placed in a 1000 ml Pyrex beaker containing 500 ml of boiling lactophenol and 50 ml of 0.2% aniline blue for approximately 25 minutes. Aniline blue in lactophenol is a routine technique to observe nematodes in plant tissue (Hooper, 1970). The terylene bundles containing the leaves were then drained and placed in cold clean lactophenol for at least 12 hours before they were again drained and unwrapped. The individual leaves were examined under a binocular microscope (x12.5) with transmitted light for the presence of eggs in the midribs and veins. FALH eggs stained blue under this treatment and the red pigment of parasitised eggs could still be distinguished. These were both recorded. Sampling of FALH summer eggs for the 1981-82 season was initiated on 26 November 1981 and continued until 28 April 1982 at approximately 14 day intervals. In all there were 13 samples on 13 dates.

An attempt was made to establish the accuracy of this method by comparison with the number of FALH nymphs and A. armatus adults that emerged from the leaves. In addition to the normal sample taken on 30 December 1981 a second identical sample was taken. The first sample was treated in the normal way but each leaf of the second sample was placed separately in a plastic petri dish containing moist filter paper. Several drops of 0.01% methoxyethyl mercury were added to each dish to prevent the growth of bacteria and fungi. The petri dishes were placed in a desiccator in a controlled temperature room at 22.5° C and were removed on 25 January 1982 when each dish and leaf was individually observed for FALH nymphs and A. armatus adults. This amount of time should exceed that necessary for an egg to hatch if laid on or before 30 December 1981.

Data Analysis. The means and variances of each sampling date were used to generate the respective indices of Taylor's power law and Iwao's patchiness regresion. An indication of the appropriate transformation of the data was ascertained from these also. The success of the

transformations was tested by calculating the correlation coefficient of the variance and mean of the treatments (Harcourt, 1961) which indicated the stability of the variance. Any significant statistical differences in egg counts in relation to height and quadrat, for four representative samples in 1980-81 and height and position, for four representative samples in 1981-82 were examined by ANOVA on the transformed data.

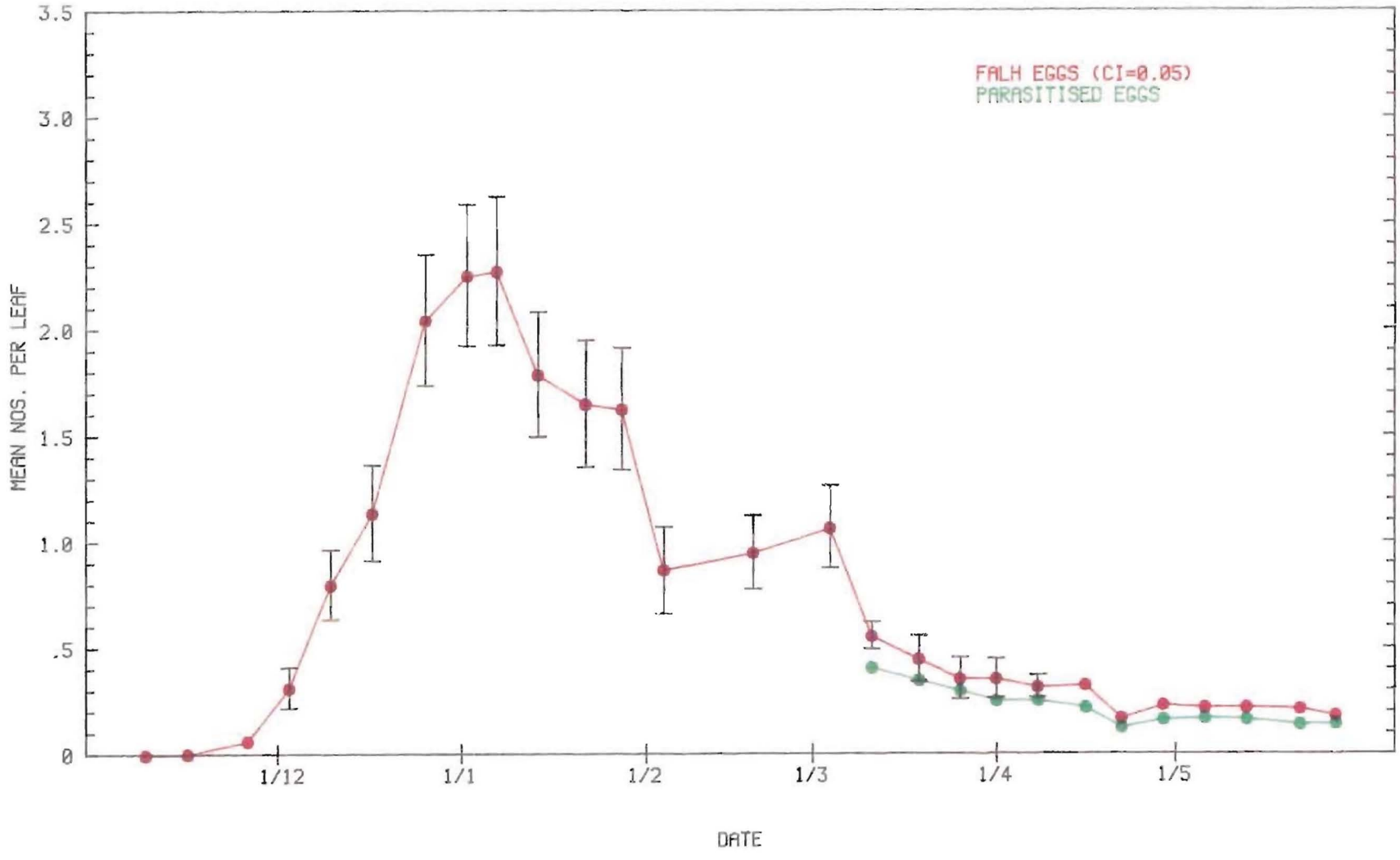
A comparison between the lactophenol/aniline blue staining method and hatching was not carried out statistically for reasons mentioned in the results.

(iii) Results and Discussion.

First Season: 1980-81. FALH eggs appeared opaquely cream in relation to the semi-translucent green tissue of the leaves when viewed with transmitted light through the binocular microscope. These eggs were clearly visible in the veins and thinner portions of the midrib and it was considered that this sampling method was accurately establishing egg numbers in these positions. However, this author was sceptical about the accuracy of egg counts where the leaf tissue became thicker, for example in the lower portion of the midrib. It was likely that eggs in this region could not be distinguished against the dense surrounding plant tissue and therefore the total number of eggs was probably underestimated by an unknown factor. Nevertheless this method proved useful in establishing the presence of FALH eggs and a relative estimate of their numbers.

Phenology. (see Figure 4.1) The first FALH eggs were observed in the cleared sample leaves on 17 November 1980. This initial appearance corresponded to the expected oviposition of eggs by FALH females. Females were first observed in leaf samples on 10 November 1980 (see Chapter 4.3) and on sticky board samples on 12 November 1980 (see Chapter 5.1). Dumbleton (1934) reported a premating period for females of an average of 7.5 days and indicated that egg laying occurred within 2 days of mating. Thus it would be expected that FALH eggs would appear in the orchard around 20 November. This sampling method was therefore ideal for establishing the initial oviposition of FALH eggs. The number of eggs sampled built up to a peak by 7 January 1981 when

FIGURE 4.1: MEAN NUMBER OF FALH EGGS AND PARASITISED EGGS PER LEAF FROM LEAF SAMPLES, 1980-81, ORCHARD 1



egg numbers were recorded at an average of 2.28 eggs per leaf. This value is likely to be an underestimate (see above). Dumbleton (1937) counted 1.1 eggs per leaf by dissection on 18 January 1935. At a comparable time in the 1980-81 season there were approximately 1.7 eggs per leaf. The increase in eggs in late February could well be an indication of third generation eggs being laid, although it could also be attributable to experimental error. There was no complementary increase in 1st instars later (see Chapter 4.3). Leaf fall started in late May and was mostly over by early June. The continuance of FALH eggs well into leaf fall was most likely the result of parasitism as a large proportion of the eggs present at this time were parasitised (see Parasitism). A large number of FALH eggs would be destroyed as the leaves fell from the trees.

Analysis of Variance. Taylor's power law (see Table 4.5) indicated the need for a transformation of $(x)^{0.4}$. This transformation proved appropriate in reducing the dependence of the variance on the mean for the northern sampling dates but a square root transformation was better for the southern sample (see Table 4.7). The analysis of variance showed that there was no difference in egg counts in relation to height and quadrat for the four samples (see Table 4.8). Further examination of the treatment means (see Appendix 4) showed no consistent pattern in egg numbers for heights although there were always fewer eggs in the southern quadrat of each sample. Only in the southern sample was any significant difference ($p < 0.005$) in egg numbers found and this was between trees. This may have been due to the different tree varieties found in the two southern rows of Orchard 1, but it was more likely due to the differences in growth and vigour of the trees brought about by the uneven stresses placed on them.

Dispersion. (see Tables 4.5 and 4.6) A contagious distribution of summer eggs was indicated by Taylor's power law ($b > 1$ at $p < 0.001$) and Iwao's patchiness regression ($\beta > 1$ at $p < 0.001$). Iwao's index of basic contagion, α, was equivalent to zero and therefore indicated that the contagious distribution was made up of single eggs for this sample. According to Iwao and Kuno (1971) this type of distribution fits the negative binomial series with a common K. This is not so common and in many cases may have resulted from the animal's response to local

Table 4.5: Results of Taylor's power law for summer egg counts, Orchard 1, 1980-81 and 1981-82.

Year	n	log a±S.E.	slope b±S.E	r^2
1980-81	28	0.436±0.048	1.135±0.032	98.0
1981-82	11	0.440±0.050	1.296±0.060	98.1

Table 4.6: Results of Iwao's patchiness regression for summer egg counts, Orchard 1, 1980-81 and 1981-82.

Year	n	intercept α±S.E.	slope β±S.E.	r^2
1980-81	28	0.048±0.059	1.493±0.054	96.7
1981-82	11	0.131±0.131	1.340±0.088	96.2

Table 4.7: Correlation coefficient (r) for the mean and variance of summer egg counts of raw and transformed data showing the transformation, Orchard 1, 1980-81 and 1981-82.

Date	Side	Raw data	Transformed data	Transformation
17.12.80	north	0.792	0.45	$(x)^{0.4}$
7.01.81	north	0.940	-0.023	$(x)^{0.4}$
7.01.81	south	0.805	-0.255	$(x)^{0.5}$
28.01.81	north	0.910	0.182	$(x)^{0.4}$
23.12.81	north	0.780	-0.299	log(x+1)
30.12.81	north	0.073	-	-
12.01.82	north	0.998	-0.07	log(x+1)
1.02.82	north	0.358	-0.013	log(x+1)

Table 4.8: F values from the analysis of variance on transformed summer egg counts, 1980-81, Orchard 1.

Source of variance	df	Date			
		17.12 (N)	7.01 (N)	7.01 (S)	28.01 (N)
Between trees					
Trees (T)	3	0.755	2.866	5.943 **[a]	2.124
Within trees					
Height (H)	1	0.025	8.616	1.943	0.277
Residual	3				
Quadrat (Q)	3	1.886	1.909	0.237	0.199
Residual	9				
H * Q	3	0.576	4.548	0.199	3.075
Residual	9				
Residual	128				
Total	159				

[a] sig at $p < 0.005$

(see Appendix 4 for tabulated means.)

heterogeneity in the habitat (Iwao and Kuno, 1971). The distributions of summer and winter eggs showed some discrepancies. Winter eggs indicated a random distribution of clumped single individuals (see Chapter 4.1) in comparison to the clumped distribution of individuals in summer. It is conceivable that the leaves in which the summer eggs were laid were inherently more heterogeneous to FALH females than branches in which the winter eggs were laid. Furthermore, actively growing transitory leaves may be more susceptible to the stresses exerted upon them in this orchard than a more stable branch. This too may have increased any heterogeneity present in the leaves to which female FALH's may have responded.

Parasitism. (see Figure 4.1) In the later summer egg samples it was observed that some FALH eggs had a red pigmentation. From 11 March 1981 until the last sample these were recorded separately from the transparent eggs previously observed. Later evidence (see results 1981-82) strongly suggested that red eggs were parasitised by A. armatus. Between 11 March and 22 May 1981 parasitism averaged 74.2% (see Figure 4.1). At these times FALH egg numbers were low, less than one third of peak numbers, and it is therefore difficult to extrapolate the significance of parasitism by A. armatus over the total range of egg numbers. Furthermore, the number of red eggs did not give an accurate indication of the number of parasitised eggs present. The red pigment in the body of parasite larva indicated the approach of pupation (Dumbleton, 1934) and the number of parasitised eggs at any one time was therefore likely to be underestimated. Results from the 1981-82 season indicated that parasitism over this period was about 100%.

Parasitised eggs appeared to be the main reason for the continual presence of eggs well into May as first instar nymphs were not observed on leaf samples after 25 February 1981 (except for one on 29 April 1981). Female FALH's were found in appreciable numbers until 13 May 1981 and were likely to be laying overwintering eggs at this stage. A. armatus adults were present to parasitise overwintering eggs laid by these females until and beyond this time (see Chapter 5.1). Therefore, the presence of parasitised summer eggs would still be expected. The continual presence of FALH eggs after late 25 February 1981 was

probably the result of the later and perhaps slower development of A. armatus larvae within them which would emerge at an appropriate time to parasitise overwintering eggs.

Second Season: 1981-82. The addition of aniline blue to the lactophenol clearing method improved the visibility of FALH eggs where dense leaf tissue had previously made observation difficult. Both the stained blue and the red pigmented eggs were clearly visible in all parts of the leaf. Care had to be taken to differentiate the egg sac of hatched eggs which remained in the leaf veins and superficially resembled the blue stained eggs.

Phenology. (see Figure 4.2) FALH eggs were first observed in the leaf samples on 11 December 1981 although the previous sampling date was 26 November 1981. The first FALH females were found in leaf samples on 19 November 1981 (see Chapter 4.3) and in sticky board samples on 26 November 1981 (see Chapter 5.1). Assuming Dumbleton's (1934) oviposition period of 9.5 days, summer eggs would expected in the orchard between 28 November and 5 December 1981. Therefore, oviposition was probably initiated closer to the sample on 26 November than the sample on 11 December 1981. As in the 1980-81 season FALH eggs showed a rapid increase in numbers to a maximum average of 3.1 eggs per leaf on 30 December 1981, a 40% increase on the previous year. This most likely reflected the better method used in 1981-82 as there were no comparative increases in the numbers of nymphs or adults (see Chapters 4.3 and 5.1). An extended period of decline followed when eggs were found in the leaves in small numbers until leaf fall was well under way on the last sampling date (24 April 1982). There was a slight increase in egg numbers in late February although not as large as in the previous season. There was no corresponding increase in 1st instars (see Chapter 4.3). Once again this could be experimental error, but the existence of this increase twice in consecutive years must add weight to the possibility of third generation eggs being oviposited. On a similar date to Dumbleton's (1937) estimate of 1.1 eggs per leaf, approximately 1.7 eggs per leaf were found in the 1981-82 season. The presence of FALH eggs in March and April was again very likely a response to parasitism (see Parasitism).

FIGURE 4.2: MEAN NUMBER OF FALH EGGS AND PARASITISED EGGS PER LEAF FROM LEAF SAMPLES, 1981-82, ORCHARD 1

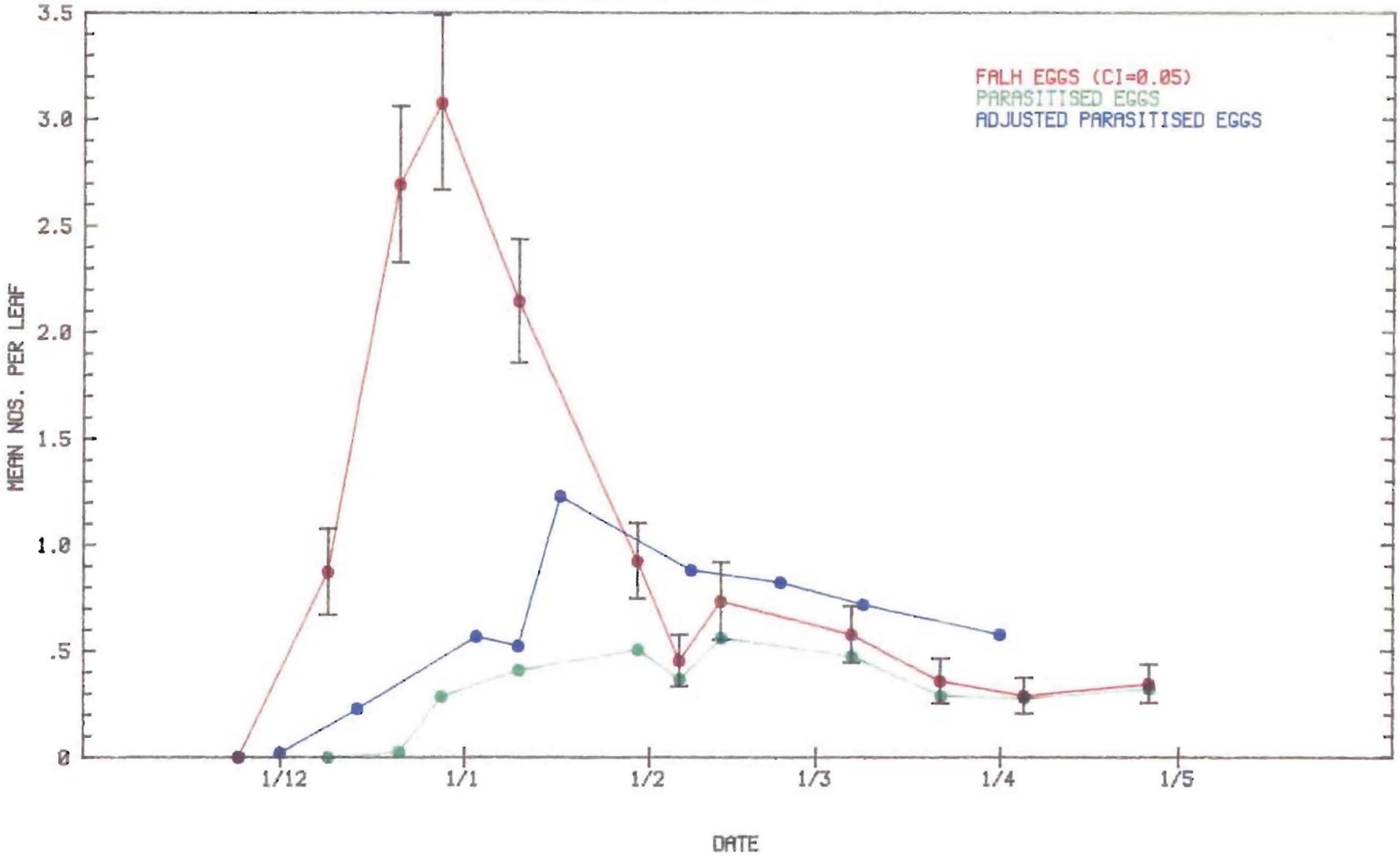


Table 4.9: F values from the analysis of variance on transformed (except 30.12.81) summer egg counts, 1981-82, Orchard 1.

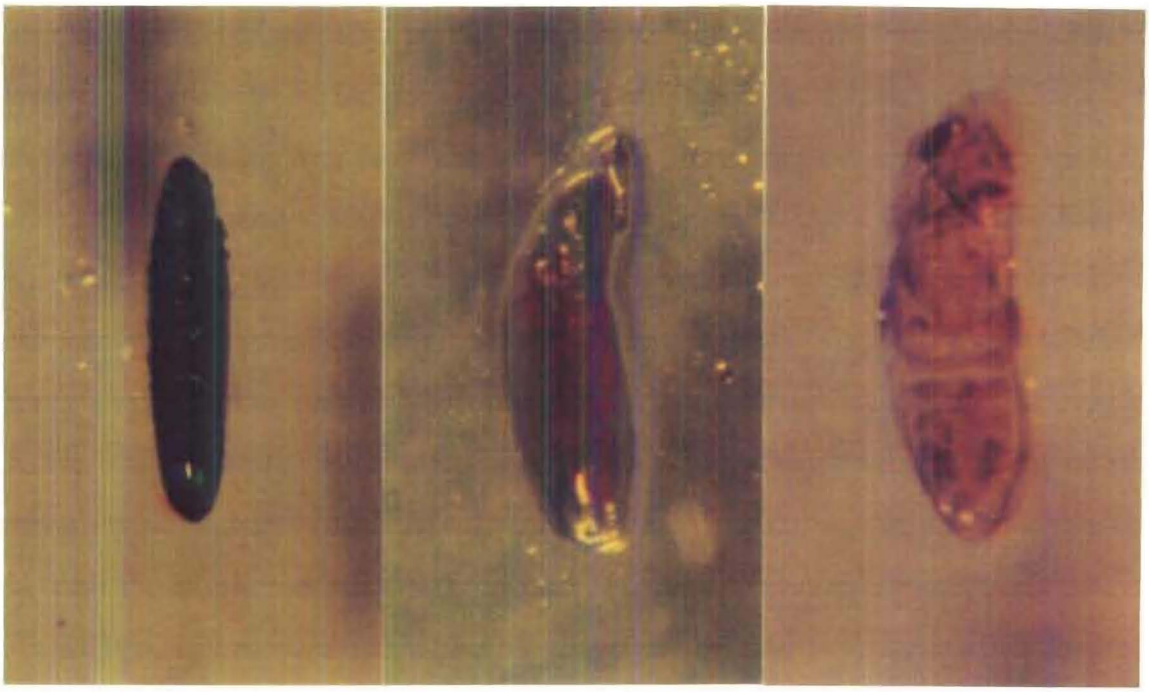
Source of variance	df	Date			
		23.12	30.12	12.01	1.01
Between trees					
Trees (T)	3	3.718	1.577	2.367	2.260
Within trees					
Height (H)	1	0.810	7.386	0.912	0.137
Residual	3				
Position (P)	1	0.0	0.510	1.668	0.077
Residual	3				
H * P	1	3.658	4.584	7.136	0.211
Residual	3				
T.H.P.L. strat	64				
T.H.P.L.units strat	80				
Total	159				

(see Appendix 4 for tabulated means.)

Analysis of Variance. Taylor's b indicated that a transformation of $(x)^{0.4}$ would stabilise the variance, but it was found that a log(x+1) transformation was the most appropriate for three sampling dates and the fourth did not need transformation. Table 4.7 shows the extent to which the variance was stabilised by the transformations. From Table 4.9 it can be seen that there were no significant differences in egg numbers in relation to height or position in the canopy of the apple trees. Examination of the treatment means for the four sampling dates (see Appendix 4) showed that there was no consistent preference of oviposition for height or position within the canopy. Therefore, in this sample, it appeared that FALH eggs were evenly distributed over the apple trees in relation to height and position in the canopy.

Dispersion. (see Tables 4.5 and 4.6) Both Taylor's b ($p < 0.001$) and Iwao's β ($p < 0.005$) were greater than unity indicating a contagious or clumped distribution of summer eggs during the 1981-82 season. The basic unit of the distribution was made up of individual eggs. This was shown by the value of α in Iwao's patchiness regression being equivalent to zero. These values were equivalent to those established for summer eggs in the 1980-81 season and probably resulted from the same circumstances.

Parasitism. (see Figure 4.2) Red pigmented eggs were first observed at a low level in the summer egg samples on 23 December 1982. After an initial increase the number remained roughly constant until the last sampling date. Closer investigation of the red eggs by binocular microscope (x50) revealed the presence of pupa within some of the eggs. This author observed a continuum of eggs from slightly red pigmented through strong red pigmented to brown eggs in which the pupa had strong parasitic characteristics (see Plate 2). An attempt was made to establish this gradation visually by colour photography but it failed due to poor developing. Dumbleton (1934) stated that the first sign of approaching pupation of A. armatus was noted by the presence of a red pigment in the larva. From this evidence it was concluded that any FALH egg showing slight to strong red pigmentation and/or a pupa with parasitic characteristics was parasitised and recorded as such throughout the whole of the 1981-82 season and the latter stages of the 1980-81 season. Figure 4.2 shows a base line of parasitism as observed



a. b. c.

Plate 2: FALH eggs, (x80 approx.) a. blue stained egg,
b. red pigmented egg,
c. parasitised egg.

in FALH eggs for the 1981-82 season.

As already mentioned, this value underestimated the number of parasitised eggs because only the parasites which had neared pupation were counted. Therefore, the third line of Figure 4.2 was probably a better indication of parasitism for any point in time. This line of adjusted parasitised eggs was reached in the following way. Adults of A. armatus were present (see Chapter 5.1) on the sticky traps some time before oviposition by FALH females occurred. Therefore, it was assumed that oviposition by the female parasites occurred as soon as oviposition by female FALH's occurred. The time from initial appearance of FALH eggs to the first appearance of parasite pupae in FALH eggs should be the approximate time for a parasite to develop from egg to pupae. On each sampling date (date 1) the number of parasite pupae were counted and the time of development subtracted so that an approximate date of parasite oviposition was established (date 2). The number of parasitic pupae on date 1 was then added to the interpolated number of parasites on date 2. Obviously, errors due to interpolation, sample timing, and development exist in this approach and the line can be considered only as a crude estimate of parasitism. Nevertheless, it was believed that this result gave a more accurate representation of FALH egg parasitism by A. armatus than did the straight forward count.

The adjusted graph showed parasitism of approximately 20% when FALH egg numbers were at their peak. This percentage increased and finally went well above 100% in the later stages of the 1981-82 season. These latter figures are obviously exaggerated but give a strong indication to the extent of parasitism throughout February, March and April. The presence of very few 1st instar nymphs after early February would support near 100% parasitism. The presence of parasites found in the leaves at this time coincided with the presence of FALH females (presumably laying overwintering eggs) and the adults of A. armatus (see Chapter 5.1).

Dumbleton (1937) established parasitism of 66% by A. armatus for summer eggs on 18 January 1935. On the same date in the 1981-82 season parasitism was 50 and 72% for the parasite egg counts and adjusted parasitised eggs respectively.

Unfortunately, the attempt to establish the accuracy of the lactophenol/aniline blue staining technique failed. When the petri dishes containing the leaves were removed for inspection it was found that many leaves had decayed. The number of hatched nymphs and the number of hatched parasite adults was approximately 1/3 and 1/2 respectively of those observed by the clearing technique. It was possible that the rotting leaf material inhibited hatching of both nymphs and parasites and that if hatched their presence was obscured by fungal growth and therefore underestimated. Due to the errors involved statistical analysis was not carried out on this data.

The adult parasite specimens collected from this study were positively identified as Anagrus armatus (Ashmead) by Mr E. W. Valentine of Entomology Division, D.S.I.R.

(iv) Summary.

In both seasons, summer FALH eggs were observed in the leaf samples soon after the first adult females were trapped in the orchard. The numbers increased to a peak and then decreased and remained in the leaf samples until late in the summer season. In both seasons there was a further slight increase in numbers some time after the first peak. This may have been the oviposition of third generation FALH eggs.

In the 1980-81 season there was no preference of oviposition for height and quadrat and in the 1981-82 season no preference for height or position in the canopy. Both Taylor's power law and Iwao's patchiness regression indicated that the population was made up of a clumped distribution and Iwao's α indicated that the basic unit of the distribution was a single egg for both seasons.

A. armatus was found parasitising summer FALH eggs. In both the 1980-81 and 1981-82 seasons this seemed to be the main reason for the continued presence of summer eggs late into the season as at this time most were parasitised. In the 1981-82 season a conservative estimate of parasitism at peak egg numbers was 20%. This increased to near 100% as the season progressed.

4.3 Leaf Sampling Directed at the Nymphal Stages.

(i) Introduction.

A leaf has often been the basis of a sampling unit for leafhopper nymphs on apple trees (Chiswell, 1964; Trammel, 1974; Madsen *et al.*, 1973; Prokopy *et al.*, 1980; Leeper, 1980) and such is the case with FALH. Ward (1936) randomly sampled 100 leaves from plots of 10 trees for FALH nymphs when investigating the effects of 6 spray treatments on a block of 'Granny Smith' trees. Other authors such as Miller (1949) and Chiswell (1964) sampled a certain number of leaves per tree. Where more accurate information was required the tree was stratified, for example into three heights by Jenkins *et al.* (1950) and quarters by Dumbleton (1937). Dumbleton examined 100 leaves of all ages *in situ* but Chiswell (1964) collected 20 leaves from each tree so that the leafhoppers could be identified and the five nymphal stages distinguished.

Removal trapping of FALH nymphs through removal of apple tree leaves would appear to satisfy the conditions proposed by Moran (1951). According to Pottinger and LeRoux (1971) a healthy apple tree of 25-30 years and 15 to 20 feet (4.6 to 6.1 m) high has about 70,000 leaves. Therefore, assuming that a leafhopper population is evenly dispersed over the whole tree, the removal of 700 leaves would be needed to cause a 1% reduction in the leafhopper population.

If the distribution of the population throughout the habitat is biased towards certain subdivisions but the sample is taken randomly, 'systematic' errors will arise (Southwood, 1978). On apple trees various pests have shown tendencies to be located in certain parts of the tree (Wilson, 1959; LeRoux and Reimer, 1959; Paradis and LeRoux, 1962; Legner and Oatman, 1962; MacLellan, 1962; Pottinger and LeRoux, 1971; Cameron and Morrison, 1974; McGroarty and Croft, 1978). For FALH Noble (1929) noted that the greatest number of nymphs were present on the leaves in the lower half of the tree, particularly in the vicinity of the main limbs and crown and Dumbleton (1937) suggested a bias of FALH nymphs for older leaves. Leafhoppers are usually found on the lower leaf surface, but as

Chiswell (1964) pointed out, the whitish spots caused by their feeding are particularly evident on the upper surface and in the earlier part of the season almost invariably indicate the presence of nymphs. To avoid bias Chiswell sampled leaves that were either concealed by other leaves, seen edge on, or in silhouette. The capture of nymphs by leaf sampling presented little difficulty to Chiswell (1964) but adults jumped and flew readily, particularly in warm weather, and the author concluded that this sampling method was not entirely satisfactory for adults. Jenkins et al. (1950) used half gallon (2.3 litres) screw top jars with 0.5 inch (0.13 mm) plaster of Paris impregnated with ethyl acetate set in the bottom. A leaf was sampled by placing it beneath the jar and carefully cutting through the petiole with sharp scissors. The more active adults still made sampling impractical in the daytime with this method and it was necessary to sample at night when the temperature dropped to 55° F (12.8°C) or lower, low enough to restrict leafhopper activity.

The primary aims of this investigation were to determine the number of FALH nymphs present and their spatial and temporal distribution.

(ii) Materials and Methods.

Leaf sampling was carried out only in the abandoned orchard, Orchard 1, (see Table 3.1) and was limited to the two rows nearest the perimeter on either side.

First Season: 1980-81.

Schedule 1. The two 'Sturmer' rows on the northern side of the orchard were divided into approximately equal blocks of 20 trees (see Figure 3.1). One tree was then randomly selected from each row of each block and subdivided following the outline given by LeRoux and Remier (1959). The crown was divided horizontally into an upper level (U), above 2 m; and a lower level (L), below 2 m. The two levels were subdivided vertically into four quadrats, corresponding to the four cardinal points of the compass and designated respectively N, S, E and W. From each of the eight subdivisions 5 healthy leaves, that were either concealed by other leaves, seen edge on, or in silhouette, were

collected and placed together in a small white paper bag.

Larvae were first observed in the orchard on approximately 18 September 1980 and sampling was initiated on 28 September 1980 followed thereafter approximately every seven days until leaf fall became extensive on 28 May 1981.

Schedule 2. The 'Statesman' and 'Sturmer' rows on the southern side of Orchard 1 were divided into approximately equal blocks of 20 trees except for the block at the western end (see Figure 3.1). Otherwise the sampling programme was identical to that described for schedule 1 except that sampling was carried out at approximately every 14 days until 19 February 1981 and on 8 April 1981.

Data Analysis. It was found that the regression lines of both Taylor and Iwao for each schedule were equivalent although for the first generation of the 2nd, 3rd and 4th instars of schedule 2 there were not enough data points to establish a regression line. Therefore the means and variances of each sampling date from both schedules were combined to establish the respective indices for Taylor's power law and Iwao's patchiness regression. This was carried out for separate instars in each generation to establish the dispersion pattern and also for combined instars to establish a suitable transformation. The total nymph counts were then transformed and tested for stability of variance by calculating the correlation coefficient for the variance and mean (Harcourt, 1961). Any significant statistical differences in total nymph counts in relation to height and quadrat were examined by ANOVA after suitable transformation.

In all schedules of both seasons the samples could not always be examined immediately after collection and were therefore refrigeratored in a sealed plastic bag at approximately 4° C. Under these conditions further development of the nymphal stages was minimised and although after some time the leaves started to rot, the nymphal instars could still be clearly distinguished. Each leaf was examined by naked eye for the presence of leafhopper nymphs. If present, the stage of a nymph was determined (under binocular microscope) using body length and development of wing buds. All leafhopper nymphs were placed into alcohol and the initial samples were rechecked for instar after the examiner had developed a familiarity with them.

Second Season: 1981-82.

Schedule 1. Four apple trees were randomly selected from the northern 'Sturmer' row, in the area encompassed by blocks 3 and 4 of Orchard 1. Each tree was divided into two levels, as in the previous season, but not into quadrats. To determine the direction of sampling on a tree, a small stick was spun horizontally and when it fell and stopped, a predetermined end pointed to the sampling direction. In this established direction, 5 healthy leaves from the inner (I) canopy and 5 healthy from the outer (O) canopy were collected at both heights. This was repeated three times for each tree. Each group of 5 leaves was placed in a labelled white paper bag. By collecting leaves that were either concealed by other leaves or seen edge on or in silhouette care was taken not to bias the samples.

Nymphs were first observed in the orchard on 1 November 1981. Sampling started on 7 November 1981 and continued until 7 April 1982 at approximately 14 day intervals. At the beginning of February 1981 a 'second growth' of new leaves occurred (Felber, 1948) and as a result on 8 and 22 February two further samples were taken. These involved the same trees as in the other samples and were divided vertically as before. The sampling direction was determined in the same manner but no allowance was made for position in the canopy. For three sampling positions, 5 old (A) and 5 new (Y) leaves were collected from any position in the canopy for both heights. There were very few new leaves present in the lower level of the trees on the northern side and therefore no new leaves were sampled from this position. Each group of 5 leaves was placed in a labelled white paper bag and taken back to the laboratory.

Schedule 2. Four apple trees were randomly selected from the southern 'Sturmer' row in the area encompassed by blocks 3 and 4 of Orchard 1. Unlike the trees in schedule 1, the trees on the south side were smaller and in the upper levels did not have a distinct inner and outer canopy. All upper leaves were as exposed as the outer leaves of the lower level. Therefore, no distinction was made between inner and outer positions in the upper level and the upper sample was taken from anywhere in the canopy. Apart from this the sampling procedure was the same as for schedule 1, for sampling in relation to both position in

the canopy and age of leaf. There were, however, adequate numbers of new leaves in the lower level of the trees in schedule 2 for these to be sampled.

Data Analysis. The indices of Taylor's power law and Iwao's patchiness regression were calculated for each instar and total instar leaf counts for each generation and schedule, from the means and variances of each sampling date excluding the samples taken on 8 and 22 February. It was found, in all but one case, that the lines describing the regression of both schedules in each generation individually, were equivalent. The exception was when there was not enough data to find a regression line for one schedule. Thus the values of Taylor's and Iwao's indices were established from the combined means and variances of the two schedules. The need for transformation of the combined nymph count and its effectiveness was established by calculating the correlation coefficient for the variance and mean (Harcourt, 1961). ANOVA was carried out on the combined nymph counts data after transformation (if possible) for height, position and age. In schedule 2 the analysis of position and height had to be carried out separately. The upper samples were compared to the lower outer samples. Likewise the analysis of height and age was carried out separately in schedule 1, as no new leaves were sampled in the lower sections of the trees. The small number of nymphs present on 15 February 1982 and after precluded them from ANOVA.

Adults.

In the process of sampling nymphs a number of adults were also collected. As has been experienced by other authors (Jenkins et al., 1950 and Chiswell, 1964) leaf samples proved unreliable for collecting active adults in the daytime. Furthermore, the number of leafhoppers caught were not likely to be a constant proportion of the population. Factors such as temperature, wind-speed and sampler dexterity would strongly effect the proportion of the population caught. Therefore, the results of these counts were not analysed in any way.

Plate 3: Adult leafhopper exoskeleton (x16 approx.)

Near the end of the 1980-81 season, what appeared to be adult exoskeletons were found in small numbers (i.e. between 1 and 5 per sample) in the leaf samples attached to individual leaves (see Plate 3). In the 1981-82 season these were counted and examined.

(iii) Results and Discussion.

First Season: 1980-81.

Phenology. Leafhopper nymphs were first observed in Orchard 1 on approximately 18 September 1980, and sampling commenced on 28 September 1980. Figure 4.3 shows the numbers of each of the five instars in sequential development. First and second instars only were present in the first sample with the numbers of the first instar having already reached their peak. Peak numbers of combined instars in the first generation were present on the first and fourth samples at over 5 nymphs per 5 leaves in schedule 1 (see Figure 4.4) and there were few left by late November. Second generation first instars were first observed in the leaf samples in late December and combined instar numbers reached 6.3 nymphs per 5 leaves in late January in schedule 1. The two peaks in numbers of each instar strongly suggested the occurrence of at least two generations during the 1980-81 season, and the extended tail of the second generation may have indicated the presence of some third generation nymphs in the population. Later instar nymphs were found in the samples in small numbers up until 4 weeks before the end of leaf fall. There appeared to be no corresponding increase in second generation 1st instar numbers with the increase in egg number in late February (see Chapter 4.2). Only one second generation 1st instar nymph was found after 25 February 1981, a time when leaf egg sampling indicated that there was still an average of about 1 FALH egg per leaf. Leaf fall started near the end of March and finished soon after the last sampling date (28 May 1981). This meant that a number of nymphs would have been lost through their host leaves falling from the tree.

There appeared to be significantly fewer nymphs on the south side of Orchard 1 in relation to the north side. This was especially true for the first generation. Although this was not tested statistically

FIGURE 4.3: MEAN NUMBER OF NYMPHS PER INSTAR
PER 5 LEAVES FOR SCHEDULE 1, ORCHARD 1, 1980-81

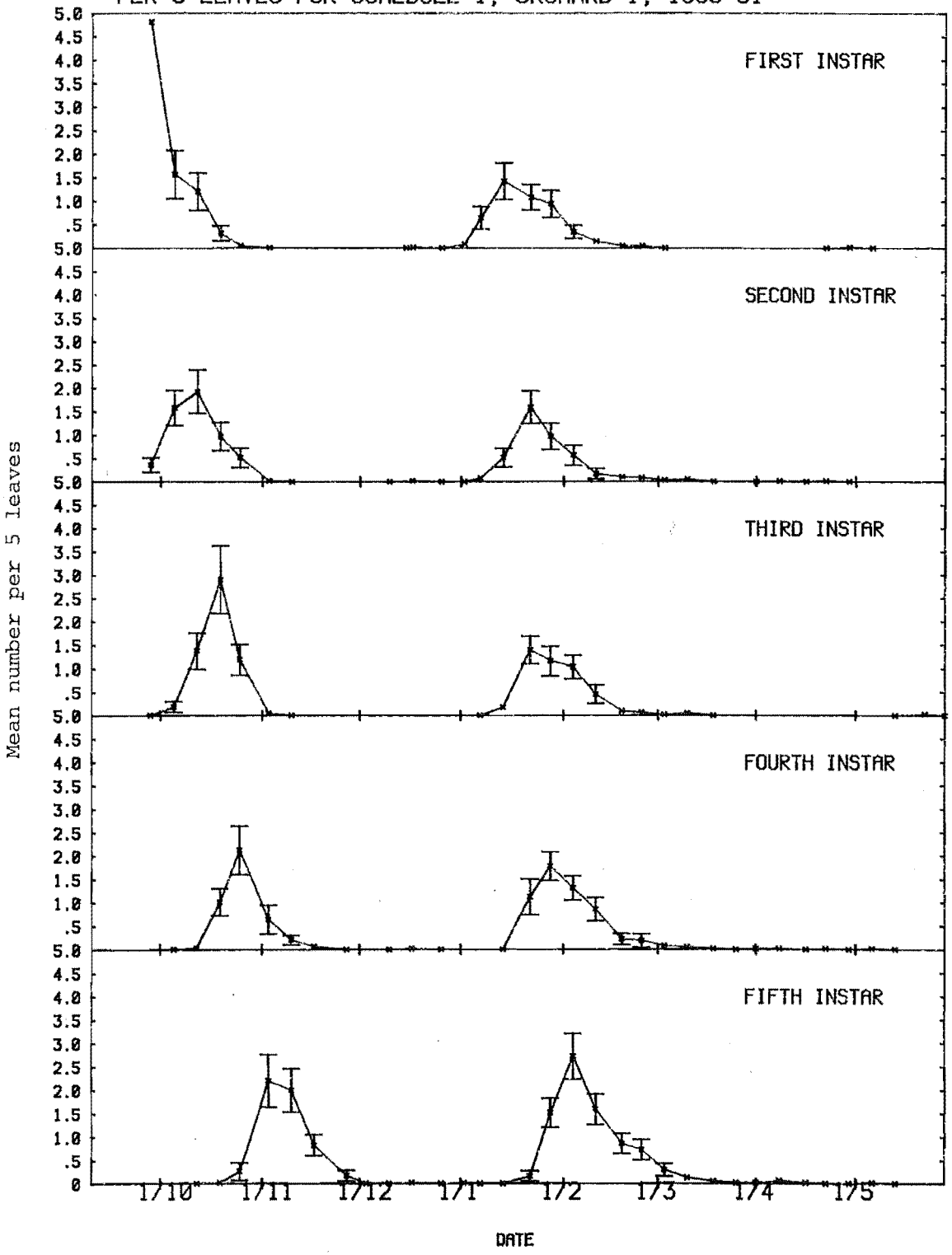
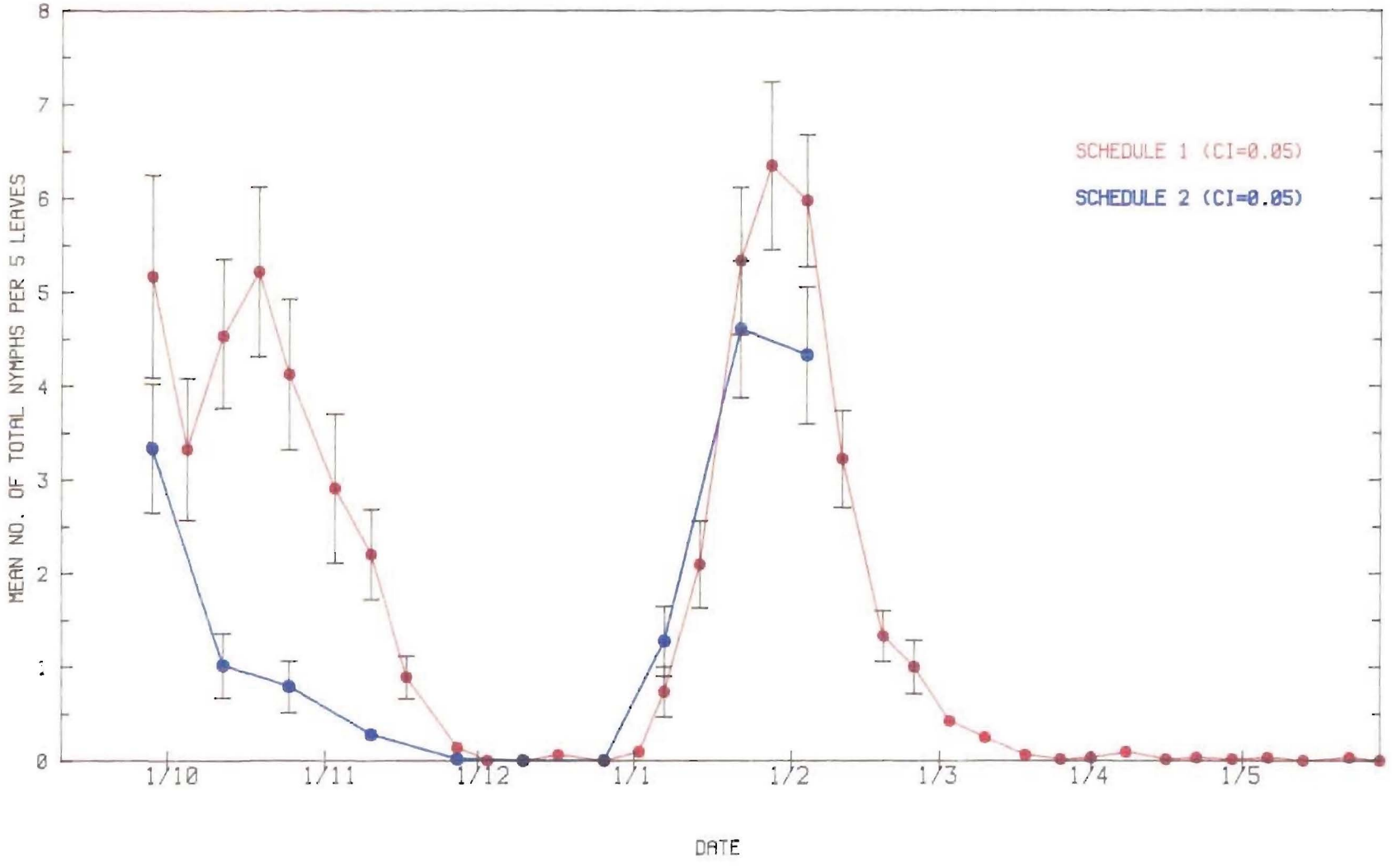


FIGURE 4.4: MEAN NUMBER OF TOTAL NYMPHS PER 5 LEAVES
FOR SCHEDULES 1 AND 2, ORCHARD 1, 1980-81.



it is obvious from Figure 4.4. There may have been several reasons for this: the trees on the northern side of Orchard 1 did not suffer so much from water stress due to the proximity of the drain and shading by the poplar shelter, it was likely that this affected the size of individual trees, their vigour and thus their carrying capacity; higher temperatures experienced on the southern side may have contributed directly to nymphal mortality as well.

Adult FALH males and females were first found in the leaf samples on 10 November 1980 and were present more or less continually up until the last sampling date on 28 May 1981. Only on four occasions, 7 and 14 January and 13 and 22 May 1981, were there no adults present in the leaf samples.

Analysis of Variance. Taylor's power law (see Table 4.10) indicated that a transformation of $(x)^{0.4}$ would be most appropriate for total nymph numbers in both sampling schedules. However, square-root transformations stabilised the variance to a greater extent on a number of sampling dates, and on one date no transformation was suitable (see Table 4.12). Certain sample dates were not subjected to ANOVA due to the excessive number of zero counts present. In schedule 1 eight sample dates were analysed. The number of nymphs was significantly different for heights on only one occasion at the 97.5% significance level (see Table 4.13). There were more nymphs in the lower level on this date. In schedule 2, of the four dates analysed the number of nymphs were significantly different for height on three occasions, all at the 97.5% significance level (see Table 4.14). In two samples there were more nymphs in the upper level but more in the lower in the remaining sample. Considering the level of significance of this variance and the lack of any consistent pattern of treatment means for levels (see Appendix 5), the data suggests that leafhopper nymphs showed little preference for any level of the apple tree over the season. These results and those of the following season differ with Noble's (1929) who noted that a greater number of nymphs were found in the lower levels. There was no significant difference in nymph counts for quadrats in either schedule and no apparent consistent pattern in the treatment means to suggest that the nymphs had any preference for cardinal direction in the tree canopy (see Appendix 5).

Table 4.10: Results of Taylor's power law for nymph counts from leaf samples of combined schedules 1 and 2, Orchard 1, 1980-81.

Instar	Generation	n	log a ±S.E.	slope b ±S.E.	r^2
1	1	8	0.749 ±0.092	1.199 ±0.043	99.2
2	1	8	0.359 ±0.053	1.118 ±0.032	99.5
3	1	7	0.497 ±0.051	1.168 ±0.032	99.6
4	1	8	0.461 ±0.176	1.164 ±0.094	96.2
5	1	10	0.497 ±0.111	1.136 ±0.048	98.6
total	1	14	0.616 ±0.074	1.198 ±0.046	98.1
1	2	15	0.301 ±0.073	1.099 ±0.033	98.9
2	2	17	0.182 ±0.053	1.046 ±0.021	99.4
3	2	15	0.119 ±0.064	1.033 ±0.025	99.2
4	2	17	0.176 ±0.091	1.058 ±0.033	98.5
5	2	18	0.175 ±0.058	1.065 ±0.024	99.2
total	2	25	0.373 ±0.052	1.108 ±0.022	99.1

Table 4.11: Results of Iwao's patchiness regression for nymph counts from leaf samples of combined schedules 1 and 2, Orchard 1, 1980-81.

Instar	Generation	n	intercept α ±S.E.	slope β ±S.E.	r^2
1	1	8	0.298 ±0.231	1.469 ±0.110	96.7
2	1	8	0.022 ±0.07	1.394 ±0.071	98.5
3	1	7	0.177 ±0.121	1.323 ±0.092	97.6
4	1	8	0.092 ±0.231	1.494 ±0.263	84.4
5	1	10	0.164 ±0.169	1.386 ±0.170	89.2
total	1	14	0.216 ±0.225	1.358 ±0.074	96.6
1	2	15	-0.049 ±0.071	1.484 ±0.103	94.1
2	2	17	0.058 ±0.048	1.127 ±0.084	92.2
3	2	15	0.033 ±0.065	1.089 ±0.099	90.3
4	2	17	0.040 ±0.110	1.128 ±0.149	79.2
5	2	18	-0.017 ±0.068	1.180 ±0.069	94.8
total	2	25	0.171 ±0.108	1.122 ±0.042	96.9

Table 4.12: Correlation coefficient (r) for the mean and variance of raw and transformed data with the transformation indicated for total nymphs on leaf samples, schedule 1 and 2, 1980-81.

Date	Raw	Transformed	Transformation
Schedule 1.			
28.09.80	0.887	0.376	$(x)^{0.4}$
12.10.80	0.472	-0.296	$(x)^{0.5}$
25.10.80	0.62	0.06	$(x)^{0.5}$
10.11.80	0.459	-0.222	$(x+1)^{0.5}$
7.01.81	0.458	-0.011	$(x)^{0.4}$
22.01.81	0.512	0.088	$(x)^{0.5}$
4.02.81	-0.431	-	-
19.02.81	0.343	-0.208	$(x)^{0.5}$
Schedule 2.			
28.09.80	0.532	-0.021	$(x)^{0.5}$
7.01.81	0.491	-0.077	$(x)^{0.5}$
22.01.81	0.49	-0.276	$(x)^{0.4}$
4.02.81	0.638	-0.324	$(x)^{0.5}$

Table 4.13: F values for the analysis of variance of total nymph counts, for heights and quadrats, on apple trees, schedule 1, 1980-81.

Source of variance	df	Date 28.09	12.10	25.10	10.11	7.01	22.01	4.02	19.2
Within trees									
Height (H)	1	2.232	0.025	0.018	8.593+[a]	3.655	2.74	0.008	0.466
Residual	7								
Quadrat (Q)	3	0.599	1.01	0.33	1.439	1.788	2.232	1.187	0.461
Residual	21								
H * Q	3	0.098	1.33	1.085	0.470	0.351	3.287	1.106	0.648
Residual	21								

[a] + $p < 0.025$

(see appendix 5 for tabulated means)

Table 4.14: F values for the analysis of variance of total nymph counts, for height and quadrats on apple trees, schedule 2, 1980-81.

Source of variance	df	Date 28.09	7.01	22.01	4.02
Within trees					
Height (H)	1	10.784+[a]	8.873+	10.091+	1.904
Residual	7				
Quadrat (Q)	3	1.144	3.070	0.452	1.877
Residual	21				
H * Q	3	0.072	1.47	3.417	0.88
Residual	19				

+[a] $p < 0.025$

(see Appendix 5 for tabulated means)

Dispersion. First Generation. (see Tables 4.10 and 4.11) For the first three instars both Taylor's b (1st: $p < 0.01$, 2nd: $p < 0.05$, 3rd: $p < 0.01$) and Iwao's β (1st: $p < 0.01$, 2nd: $p < 0.01$, 3rd: $p < 0.05$) had values that were significantly greater than unity. Iwao's α was equivalent to zero. Therefore the dispersion of the first three instars was best described by these indices as being contagious with the basic component of the distribution being individual nymphs. This may have been a reflection of the dispersion pattern of the overwintering eggs which were described by a random distribution of clumps of eggs for the following winter (see Chapter 4.1). As the nymphs approached the later instars the dispersion pattern became more random. Movement away from a contagious distribution may be the result of nymphs making better use of their environment. Taylor's b was equivalent to unity for the 4th and 5th instars indicating a random distribution and Iwao's β was equivalent to one for the 4th instar but greater than one ($p < 0.05$) for the 5th instar. The discrepancy between Taylor's b and Iwao's β for the 5th instar is difficult to explain and may be due to the theoretical differences in these two approaches. It was possible that the distribution of the 5th instar was intermediate between random and contagious and that the two indices reflect this by their disagreement. Iwao's α was equivalent to zero

for both the 4th and 5th instars indicating distributions made up of single individuals.

Second Generation. (see Tables 4.10 and 4.11) The first instar of this generation had a contagious distribution with the basic component of one individual nymph. This was shown by the values of b ($p < 0.05$) and β ($p < 0.001$) being significantly greater than one and α being equivalent to zero. The dispersion pattern of summer eggs was also described by these indices and therefore it was expected that the newly hatched first instars would have a similar distribution. The second instar was respectively described as having a contagious and random distribution by b being greater than one ($p < 0.05$) and β being equivalent to one. This may show an intermediate pattern of distribution between the contagious 1st instars and the random distribution of the following instars. The third and fourth instars had dispersed further apart to be described by a random pattern. The values of b and β for these instars were equivalent to one and likewise the values of α were equivalent to zero. The values of b ($p < 0.05$) and β ($p < 0.05$) were greater than 1 for the fifth instar indicating a contagious distribution with the basic component of the distribution an individual nymph (α was equivalent to 0). This change of distribution from the middle instars may be explained by a response to local heterogeneity in the habitat (Iwao and Kuno, 1971). Two factors may have brought about an increase in heterogeneity in the environment for the fifth instar in relation to the others. First; new leaves, from a resumption in active growth often called the 'second growth' (Felber, 1948) were present over the period that second generation fifth instars were prevalent. Secondly, leaf fall, which started about the end of March would have influenced the 5th instar more than the 2nd, 3rd or 4th.

Second Season: 1981-82.

Phenology. FALH nymphs were first observed in Orchard 1 on 1 October 1981. Figure 4.5 shows the two distinct peaks and the consecutive development of each instar. First and second instars were both present in the first sample but neither appeared to have reached their peak numbers. First generation total nymph counts peaked at over 4 nymphs per 5 leaves in mid October (see Figure 4.6) and had mostly

FIGURE 4.5: MEAN NUMBER OF NYMPHS PER INSTAR
PER 5 LEAVES FOR SCHEDULE 1, ORCHARD 1, 1981-82

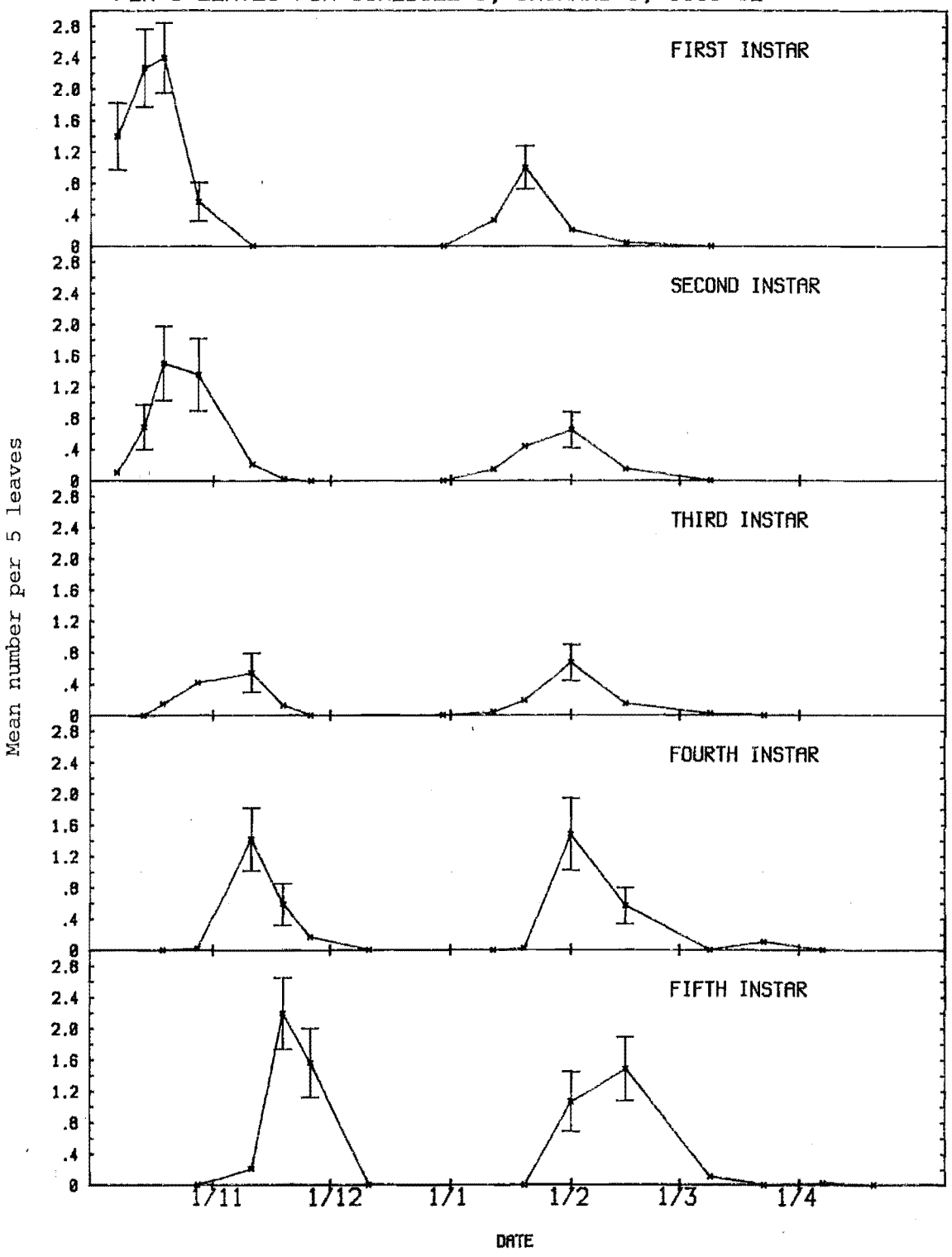
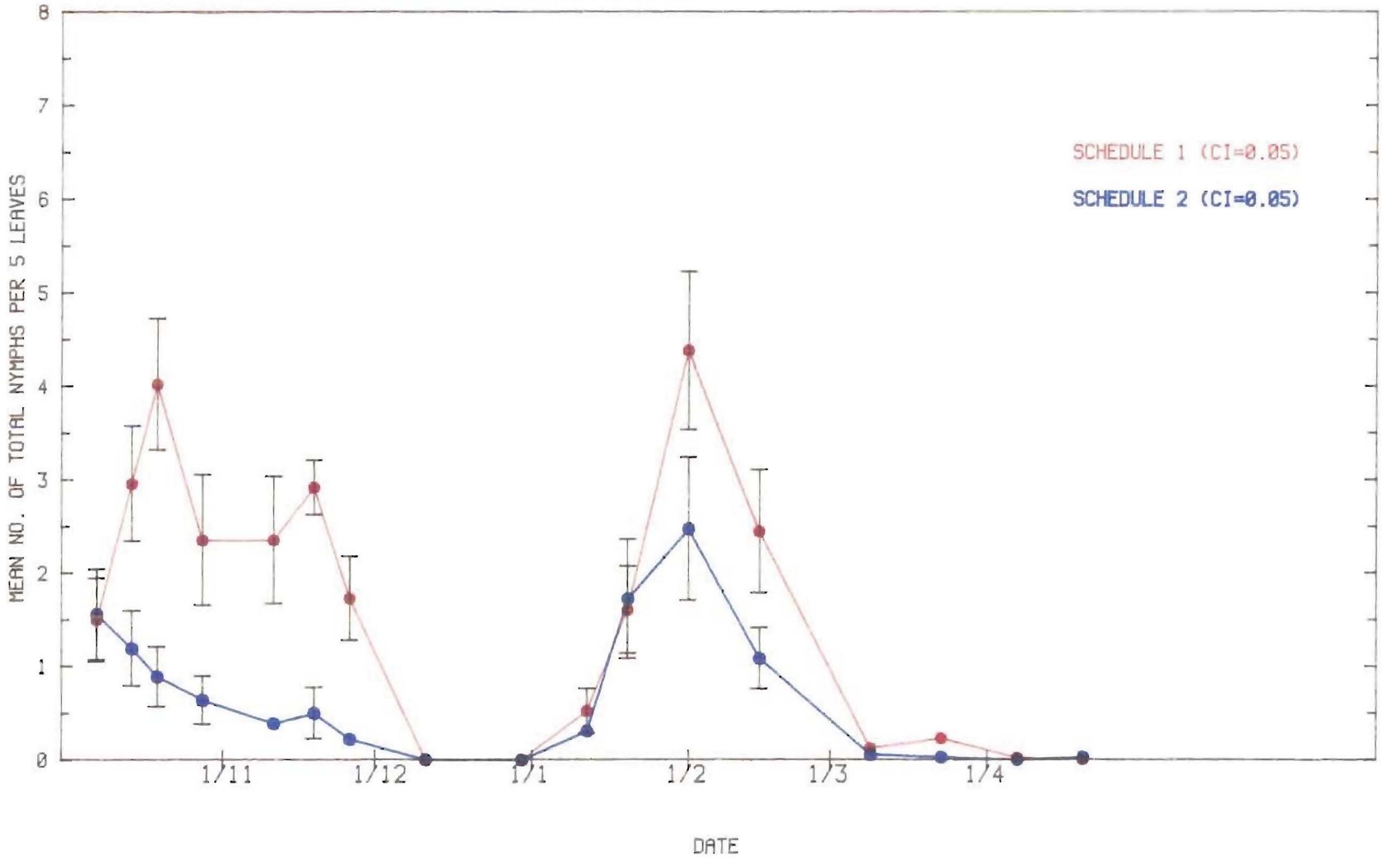


FIGURE 4.6: MEAN NUMBER OF TOTAL NYMPHS PER 5 LEAVES
FOR SCHEDULES 1 AND 2, ORCHARD 1, 1981-82.



disappeared in the samples by early March. Second generation 1st instars were first recorded in late December and total nymph counts peaked again at just over 4 nymphs per 5 leaves in late January. These had virtually disappeared by early March although small numbers were found up until the last sample date (28 April 1982). The two distinct peaks clearly showed the presence of two generations of FALH in this orchard. The presence of a single second instar nymph on 28 April 1982 in schedule 2 would strongly suggest that a third partial brood had occurred. It was unlikely that such an early instar could be attributable to late eggs of the 2nd generation.

In this season too, there appeared to be significantly fewer nymphs on the south side of Orchard 1 in relation to the north side (see Figure 4.6). This was probably due to the same reasons discussed for the previous season.

The first adults of both sexes were found in the leaf samples on the 19 November 1981 and continually throughout the season until the last sampling date on the 28 May 1982.

Analysis of Variance. Taylor's power law (see Table 4.15) indicated that $(x)^{0.6}$ and $(x)^{0.4}$ would be appropriate transformations for the first and second generation total nymph counts respectively. However, a number of dates needed no transformation and the square root and log transformations proved to be more suitable for stabilising the variance in some samples. On two occasions no transformation was found that would stabilise the variance but analysis of variance was still carried out (see Table 4.17). In schedule 1 there was no significant difference in nymph numbers in relation to height or position for the 7 sampling dates analysed (see Table 4.18). Furthermore, there was no consistent pattern of nymphal preference revealed in the untransformed treatment means found in Appendix 5. Likewise, in schedule 2 there was no significant difference in height with nymph counts and only on one occasion was there a significant difference ($p < 0.01$) in position in the canopy (see Table 4.19). On this sampling date there were significantly more nymphs on the inside lower leaves than on the outside lower leaves. Untransformed treatment means did not show any consistent pattern for combined nymph counts for either height or position for schedule 2. Therefore, it could be concluded that over

Table 4.15: Result of Taylor's power law for nymph counts from leaf samples of combined schedules 1 and 2, Orchard 1, 1981-82.

Instar	Generation	n	log a±S.E.	slope b±S.E.	r^2
1	1	8	0.180 ±0.060	1.048 ±0.048	98.7
2	1	10	0.350 ±0.089	1.157 ±0.054	98.3
3	1	9	0.237 ±0.180	1.087 ±0.078	96.5
4	1	6	-0.220 ±0.092	0.899 ±0.044	99.0
5	1	6	0.254 ±0.083	0.964 ±0.060	98.5
total	1	14	0.257 ±0.065	1.232 ±0.076	95.7
1	2	8	0.143 ±0.115	1.055 ±0.066	97.7
2	2	9	0.302 ±0.227	1.037 ±0.108	92.9
3	2	8	0.019 ±0.114	0.998 ±0.051	98.4
4	2	8	0.147 ±0.135	1.066 ±0.062	98.0
5	2	8	0.274 ±0.062	1.110 ±0.030	99.6
total	2	14	0.332 ±0.077	1.125 ±0.037	98.8

Table 4.16: Result of Iwao's patchiness regression for nymph counts from leaf samples of combined schedules 1 and 2, Orchard 1, 1981-82.

Instar	Generation	n	intercept α ±S.E.	slope β ±S.E.	r^2
1	1	8	0.152 ±0.125	1.035 ±0.090	95.7
2	1	10	-0.123 ±0.067	1.656 ±0.093	97.5
3	1	9	-0.080 ±0.124	1.849 ±0.482	67.8
4	1	6	-0.059 ±0.098	1.354 ±0.153	95.1
5	1	6	0.398 ±0.124	0.926 ±0.110	94.6
total	1	14	0.053 ±0.200	1.222 ±0.101	92.5
1	2	8	0.040 ±0.121	1.115 ±0.262	75.1
2	2	9	0.290 ±0.238	1.113 ±0.768	23.1
3	2	8	-0.011 ±0.049	1.007 ±0.164	86.3
4	2	8	-0.115 ±0.100	1.442 ±0.162	93.0
5	2	8	-0.069 ±0.073	1.384 ±0.092	97.4
total	2	14	-0.009 ±0.102	1.276 ±0.062	97.3

Table 4.17: Correlation coefficient (r) for the mean and variance of raw and transformed data with the transformation indicated for total nymphs on leaf samples, schedule 1 and 2, 1981-82.

Date	Raw	Transformed	Transformation
Schedule 1.			
7.10.81	0.146	-	-
19.10.81	-0.134	-	-
11.11.81	0.837	?	?
26.11.81	0.502	-0.280	$(x)^{0.5}$
20.01.82	0.482	0.134	$(x)^{0.4}$
1.02.82	0.398	-0.248	$(x)^{0.5}$
8.02.82	0.558	0.073	$(x)^{0.5}$
15.02.82	-0.137	-	-
Schedule 2.			
7.10.81	0.916	-0.497	log(x+1)
20.01.82	0.832	?	?
1.02.82	0.801	0.184	$\log(x+1)^{0.5}$
8.02.82	0.897	-0.237	$(x)^{0.5}$
15.02.82	0.397	-0.149	$(x)^{0.5}$

Table 4.18: F values for the analysis of variance of total nymph counts, for heights and position in apple trees, schedule 1, 1981-82.

Source of variance	df	Date 7.10	19.10	11.11	26.11	20.01	1.02	15.2
Within trees								
Height (H)	1	6.400	0.070	1.750	1.123	2.178	1.402	7.737
Residual	3							
Position (P)	1	1.154	0.640	0.288	0.912	0.013	0.317	2.530
Residual	3							
H * P	1	12.366+[a]	2.689	4.309	0.032	0.375	0.064	0.036
Residual	3							

+[a] $p < 0.025$

(see appendix 5 for tabulated means)

Table 4.19: F values for the analysis of variance of total nymph counts, for height and position in apple trees, schedule 2, 1981-82.

Source of variance	df	Date 7.10	20.01	1.02	15.02
Within trees					
Height (H)	1	3.837	0.058	3.450	0.617
Residual	3				
Quadrat (Q)	1	0.290	2.689	1.755	30.828*[a]
Residual	3				

*[a] $p < 0.01$

(see Appendix 5 for tabulated means)

Table 4.20: F values for the analysis of variance of transformed total nymph counts, for height and age in apple trees, schedules 1 and 2, 8 February 1982.

Source of variance	df	Schedule 1	Schedule 2
Within trees			
Height (H)	1	0.000	0.286
Residual	3		
Age (A)	1	1.249	10.108
Residual	3		
H * A	1	-	2.789
Residual	3		

this period of time there was no preference by FALH nymphs for height or position in the apple trees and on any particular date it is likely that this is true also.

FALH nymphs appear to have some preference for the age of leaf. Although in neither sample on 8 February 1982 was there any significant difference in nymph counts (see Table 4.20) there were more nymphs on older leaves in both schedules. This backs up the claim by Dumbleton (1937) that older leaves are preferred by FALH nymphs. It is possible that these results are a reflection of the lack of time available for nymphs to move onto the new leaves.

Dispersion. First Generation. (see Tables 4.15 and 4.16) The indices of nymphal dispersion were not compatible with those from the previous season. In the first generation all instars showed a random distribution (b and β were equivalent to unity) except for the 2nd instar ($b > 1$ at $p < 0.05$, $\beta > 1$ at $p < 0.001$) which indicated a slightly contagious distribution. There is no obvious reason why, after being randomly distributed during the first instar, 2nd instar nymphs should aggregate and then revert back to a random distribution in the 3rd instar. Apart from the 5th instar, the basic unit of the distributions was a single nymph as expressed by α being equivalent to zero. In the case of the 5th instar α was greater than 0 ($p < 0.05$) indicating that the basic component of the distribution was a cohesive group of individuals.

Second Generation. In the second generation the basic component of the distributions was always one nymph (α was equivalent to zero) and the 1st, 2nd and 3rd instars were described best by a random dispersion pattern (b and β were equivalent to 1). Although in the 4th instar b was equivalent to 1, β was greater than 1 ($p < 0.01$) indicating a random and contagious distribution respectively. In the 5th instar both b ($p < 0.05$) and β ($p < 0.01$) were greater than one indicating a contagious distribution. It seems likely that the dispersion of the 4th instar was intermediate between the random distribution of the earlier instars and the aggregated distribution of the 5th instar and was thus described differently by these two indices. Alternatively, the discrepancy could be due to the theoretical differences between the two approaches. The aggregation of the later instars in this

generation may have been for the same reasons as the second generation 1980-81. It was surprising that the 1st instars of both generations were randomly dispersed after the clumped dispersion patterns of the overwintering (see Chapter 4.1) and summer eggs (see Chapter 4.2). This may indicate the ability of 1st instars to quickly disperse over the whole tree to make best use of the environment. In the previous season this did not happen as rapidly.

In general the dispersion of nymphs in the 1981-82 season was more random than the 1980-81 season. The reasons for this are not immediately clear but may be due to a number of factors. In the 1980-81 season the extent of powdery mildew was greater than the following season. This was shown by the increase in number of leaves per cluster in the 1981-82 season (Tomkins, pers. comm.). The fewer and less healthy leaves of the 1980-81 season would have increased the heterogeneity of the environment experienced by FALH nymphs. The fungicide application in November 1981 may have enhanced this. Other differences that may have influenced the different dispersion patterns of the two seasons were the paucity of fruiting clusters (Tomkins, pers. comm.) and the shorter growing season of 1981-82. Lastly it was possible that the differing dispersion patterns over the two seasons were a reflection of the two sampling plans used.

Predation. The first adult exoskeleton was observed in the leaf samples on 11 November 1981, followed by a second approximately one month later. A total of 23 were found throughout the season with the greatest numbers (up to 7 on one occasion) being found in March and April. Closer examination of these exoskeletons revealed what appeared to be spider webbing wrapped around approximately 57%. This would suggest that predation by spiders exists in the orchard but its importance could not be determined from these results. Verification of spider predation was established in the laboratory. During the developmental studies (see Chapter 6) spiders were observed catching and eating FALH adults in the seedlings covered by perspex sleeves (see Plate 4). The results of feeding by the spiders left adult exoskeletons similar to those found in the leaf samples. Mr S. Pollard identified one of these predatory spiders as Episinus sp. (Theridiidae). It was unlikely that these spider specimens were brought back from the orchard in the process of sampling so the

Plate 4: Spider (*Episinus* sp.) devouring FALH adult (x16 approx.)

identity of the predatory spiders in the orchard was uncertain. A number of species of spiders were likely to have captured and devoured leafhoppers in the abandoned orchard.

(iv) Summary.

Nymph counts from leaf samples over both seasons showed the sequential development of the five instars over two generations. The presence of nymphs late in the season may have indicated of a partial third generation. Peak total nymph counts were 5 nymphs per 5 leaves and 4 nymphs per 5 leaves for the first generation and 6.3 nymphs per 5 leaves and 4 nymphs per 5 leaves for the second generation of both seasons respectively. Fewer nymphs were found on the south side of the orchard.

There was no consistent preference for nymph position in the tree in relation to height or quadrat in the first season and height or position in the canopy in the second season. Nevertheless, in the first season there were significantly more nymphs at different heights on occasions. In general the nymphs showed a contagious or random distribution with the basic component an individual. The descriptions of dispersion of the first season were more consistent with the knowledge of the biological system. In the second season the distribution of nymphs was, overall, more random for reasons discussed.

Predation by spiders on adult FALH adults was probably common in the orchard.

Chapter V.

SAMPLING THE ADULT STAGE OF FALH.

5.1 Sticky Board Sampling.

(i) Introduction.

In the previous section it was stated that sampling of leafhopper adults on trees was difficult and as a result a number of authors have neglected this life stage for the ease of sampling nymphs (e.g. Dumbleton, 1937; Marshall et al., 1942; Miller, 1949; Chiswell, 1964). Nevertheless, sampling of adult leafhoppers on trees has occurred although almost all the methods give only a relative estimate of the population size.

Jenkins et al. (1950) described a method of sampling FALH adults that could establish absolute population estimates if the number of leaves per unit area was known. This has already been described (see Chapter 4.3) and although not impracticable, the method severely restricts the time of sampling. The pooter (or aspirator) has been used to collect leafhopper adults (Hartzell, 1937), but as a sampling device preliminary work by this author found it to be extremely time consuming and tedious. Relative estimates of leafhopper populations on trees have been established by the use of the sweep net (Schoene, 1930; Claridge and Wilson, 1976) but the accuracy of this method is influenced by, among other things, temperature, wetness and windspeed (Southwood, 1978).

Sticky boards have been used extensively to successfully sample leafhopper vectors associated with various diseases of peach (e.g. Palmiter et al., 1960; Wilde, 1962; Rice and Jones, 1972; McKenzie and Bierne, 1972; Taboada et al., 1975; Ball, 1979; McClure, 1980) but it was not until later that the sticky board was critically compared with other sampling methods (Purcell and Elkinton, 1980). In their paper Purcell and Elkinton compared the sweep net, the D-Vac suction collector, sticky traps and 'knockdown onto a ground cloth with

pyrethrin mist'. Although not all of their work was immediately applicable to sampling FALH adults from apple trees, much of it gave a good indication of the relative use of each sampling method in an arboreal habitat. In their conclusion they stated that sticky traps yielded the highest number of leafhoppers in the cherry foliage for the least amount of labour.

Sticky traps are subject to many of the same limitations as the sweep net and are also influenced greatly by flight behaviour (Purcell and Elkinton, 1980). Any sort of continuous trapping method is subject to a number of other deficiencies as well, for example vandalism or any factor such as rain, sprinkler irrigation, or high winds that cause loss or damage to a sticky trap which cannot then be replaced. Most of the above authors have used coloured sticky traps to sample leafhoppers. The behavioural response of insects to these is poorly understood and presents problems in interpreting the significance of trap catches (Purcell and Elkinton, 1980). Nevertheless sticky traps have often been preferred to other methods because of their low cost and ease of handling (Taboada et al., 1975) and they provide a continuous record of leafhopper abundance and activity (Purcell and Elkinton, 1980).

Yellow has been the most commonly used colour on sticky board traps, probably as it has been found to be most attractive to a number of leafhopper species (Wilde, 1962; Alverson et al., 1977; Ball, 1979). Prokopy (1972), when studying the response of apple maggot flies to rectangles of different colours and shades, concluded that the yellow colour constituted a 'supernormal' foliage-type stimulus eliciting food seeking behaviour. Yellow surfaces strongly reflect those visible wavelengths predominantly reflected by green leaves (Prokopy et al., 1975).

The only reference found to sampling leafhoppers by sticky traps on apple was that by Seyedoleslami (1978). That author used yellow galvanised tin sticky boards (216 x 279 mm) covered with 'Stickem' special to estimate the activity and distribution of T. pomaria in apple orchards in U.S.A. For FALH there has been no published information on sampling by sticky traps. Penman (unpubl.) found that greater numbers of FALH adults were caught on yellow sticky boards in

preference to blue, black, green, red and white; and Tomkins (unpubl.) found more FALH adults on yellow pyramid traps in preference to black, white, green and red. In neither of these data sets was there any statistically significant preference for colour by the leafhoppers.

Mymarid parasites have been monitored using sticky traps by Kido et al. (1983).

The aims of this section of work were limited to investigating the broad trends of the FALH adult population and any aspects that may be important in their management. This was carried out in three different orchards over two seasons (see Table 3.1). In Orchard 1, a population of leafhoppers was observed under uncontrolled circumstances; in Orchard 2, the leafhoppers were re-invading a previously controlled habitat and in Orchard 3, the population was under severe restraint through normal commercial management.

(ii) Materials and Methods.

Yellow sticky boards were used to sample adult leafhoppers (including FALH) in the three orchards described in Chapter 3. All boards were hard-board rectangles (250 x 200 x 5 mm) and were painted with several coats of 'Canary Yellow' super enamel (Dulux New Zealand Ltd). Both sides of each board were covered with 'Tack-trap' (Animal Repellents, Inc. Griffin) which is reputed to be non-drying, non volatile, colourless, odourless and has no known repellent or attractive properties. It supplies permanent tack for trapping light-weight insects. A single clear 'Mylar' (DuPont, Circleville) acetate sheet was placed on both sides of the board which was covered with a further layer of Tack-trap. The use of clear acetate sheets overcame the need to remove the sticky boards from the orchard each time a sample was made. The spectral reflectance of the yellow sticky boards without Tack-trap, with Tack-trap alone and with Tack-trap and acetate sheets is compared in Chapter 5.2.

In each orchard the sticky boards were hung on apple trees at approximately 1.75 m (1980-81) and 1.9 m (1981-82) from the ground, halfway between the trunk and the outside of the canopy. To service the sticky boards the acetate sheets were removed and placed trap side

upwards, on a sheet of lined computer paper (the lines were 10 mm apart). The sheet of computer paper was then rolled into a cylinder and stapled at both ends to secure it in this position. An acetate sheet was then replaced on the board and covered with Tack-trap. In the laboratory the acetate sheets (unrolled) were examined for leafhoppers under a binocular microscope using the lines of the backing computer paper as a guide.

Identification of the leafhoppers was based on the paper by Knight (1976). According to this paper there are 13 species in six genera of the subfamily Typhlocybinae represented in New Zealand, of which eight are definitely found in the Christchurch region. The species of the genera Kybos are very restricted in their host range and were not seen in this study. Eupteryx melissae, Zygina dumbletoni and Ribautiana tenerrima were easily distinguished by their colour, size and body markings after being checked by Knight's key. The species Zygina zealandica was described by Knight (1976) as being variable in size and colour although the male genitalia of all forms were identical, it therefore caused problems with identification. In this study a number of males following Knight's general description were found to have the aedeagal form of Z. zealandica. Because of the limitations of time every individual that followed this description could not be definitively identified but it was likely that they were this species and therefore were described as such. There were no other species described by Knight (1976) in the Christchurch area that could be confused with this description. Another important taxonomic problem existed in the separate identification of FALH and T. lethierryi. These two species have identical external characteristics and can only be differentiated in reference to the aedeagus. Although T. lethierryi has not been recorded on apple, it was important to ascertain the numbers of this species that were included in the sticky board samples. An experiment to determine this is described in this chapter.

Because of the small size of A. armatus and the difficulty in establishing correct identification (there are few specialists of this group in New Zealand) the parasite results cannot be considered definitive. There are probably similar species of this group parasitising other leafhoppers in the orchards. Nevertheless, a familiarity of those adults identified correctly in other studies

helped to establish what was thought to be a reasonable reflection of the number of A. armatus adults caught on the sticky boards.

The presence of parasitism by Aphelopus typhlocybae Muesbeck on adult FALH's caught on the sticky boards was noted. The parasite larva becomes externally observable when the leafhopper reaches maturity (Dumbleton, 1937).

First Season: 1980-81.

The sticky boards were placed in the orchards in accordance with the limitations and objectives discussed in Chapter 3.

Orchard 1. On 14 October 1980 when the later instars were becoming common in the leaf samples, four yellow sticky boards were placed inside Orchard 1. Two were placed on the southern side: one in each of blocks 1 and 4 (see Figure 3.1) and two on the northern side: again one in each of blocks 1 and 4. On the same date two other boards were placed in the blackberry outside the northern orchard boundary in positions equivalent to blocks 1 and 4. These were hung at a height of approximately 0.5 m. At a later date (10 December 1980) four further sticky boards were hung within the orchard: two on the southern side; one in each of blocks 2 and 3 and two on the northern side; again one in each of blocks 2 and 3. A further sticky board was placed in the blackberry outside the northern border on this date, in a position equivalent to block 2. The acetate sheets were changed at approximately weekly intervals and sampling continued until mid July inside, and early October outside the orchard. On each sticky board the number of adult FALH, (both male and female) and other leafhopper species (not sexually differentiated) were counted. For approximately every second sampling date the number of adults of A. armatus found on the sticky boards were also counted. These were not separated into sexes.

Orchard 2. Nine sticky boards were hung within this orchard on 15 October 1980. Three were placed at the south-western end in the first 'Sturmer' row, three were placed at the north-eastern end in the fourth 'Cox's Orange' row and three were placed in approximately the middle of the orchard in the fourth 'Sturmer' row (see Figure 3.2). Each group of three boards were arranged evenly across the width of the orchard.

In addition one was hung on each of the three self seeded apple trees outside the orchard on the southern side. The acetate sheets were changed at approximately weekly intervals and sampling continued up until early July. Only adults of FALH were counted (without sexual differentiation).

Orchard 3. Four sticky boards were first placed within this orchard on 14 October 1980, one in the proximity of each of the four corners. On the same date two were hung at a height of approximately 1 m in the blackberries on the inside of the orchard at the northern end (see Figure 3.3). Initially the acetate sheets were changed at approximately 7 day intervals until 3 December 1980. After that time the boards were sampled at approximately 14 day intervals. All species of leafhoppers were counted without sexual differentiation.

Second Season, 1981-82.

In this season an attempt was made to reduce the number of samples taken in the previous season to save time for other investigations.

Orchard 1. On both sides of this orchard three yellow sticky boards were placed systematically (five trees between each) in the outer 'Sturmer' row in the area encompassed by blocks 3 and 4 on 11 November 1981 (see Figure 3.1). At this time the latter instar nymphs were prominant in the leaf samples. The three yellow sticky boards that had been placed outside the orchard in the previous season were replaced in the same position on the same date. The acetate sheets of all traps were changed at approximately weekly intervals up until 30 April inside and 28 May 1982 outside the orchard. All leafhoppers trapped on the yellow sticky boards were counted in the laboratory and for part of the season the sexes of FALH were differentiated. For approximately every second sampling date the number of A. armatus adults present on the acetate sheets were also counted.

To accurately determine the number of FALH adults, as opposed to T. lethierryi present in the orchard, acetate sheets removed from the orchard on 11 December 1981 were subsampled. At this time the number of adults trapped were near maximum for the first generation. As each acetate sheet had been placed upon lined (10 mm apart) computer paper these lines were used to define an area of the acetate sheet for

subsampling. Four areas defined by these lines were randomly selected. This represented approximately 20 percent of the trapping area. From each section every male (or male abdomen) was removed and placed head down in melted clear paraffin wax, so that when the wax solidified the genital capsule of the leafhopper was uppermost. The aedeagus of each individual was then observed under binocular microscope and each species was differentiated by using the descriptions of Knight (1976). Traps from inside the orchard were subsampled in this way, but as there were fewer Typhlocyba spp. adults trapped outside the orchard the identification of every male was checked.

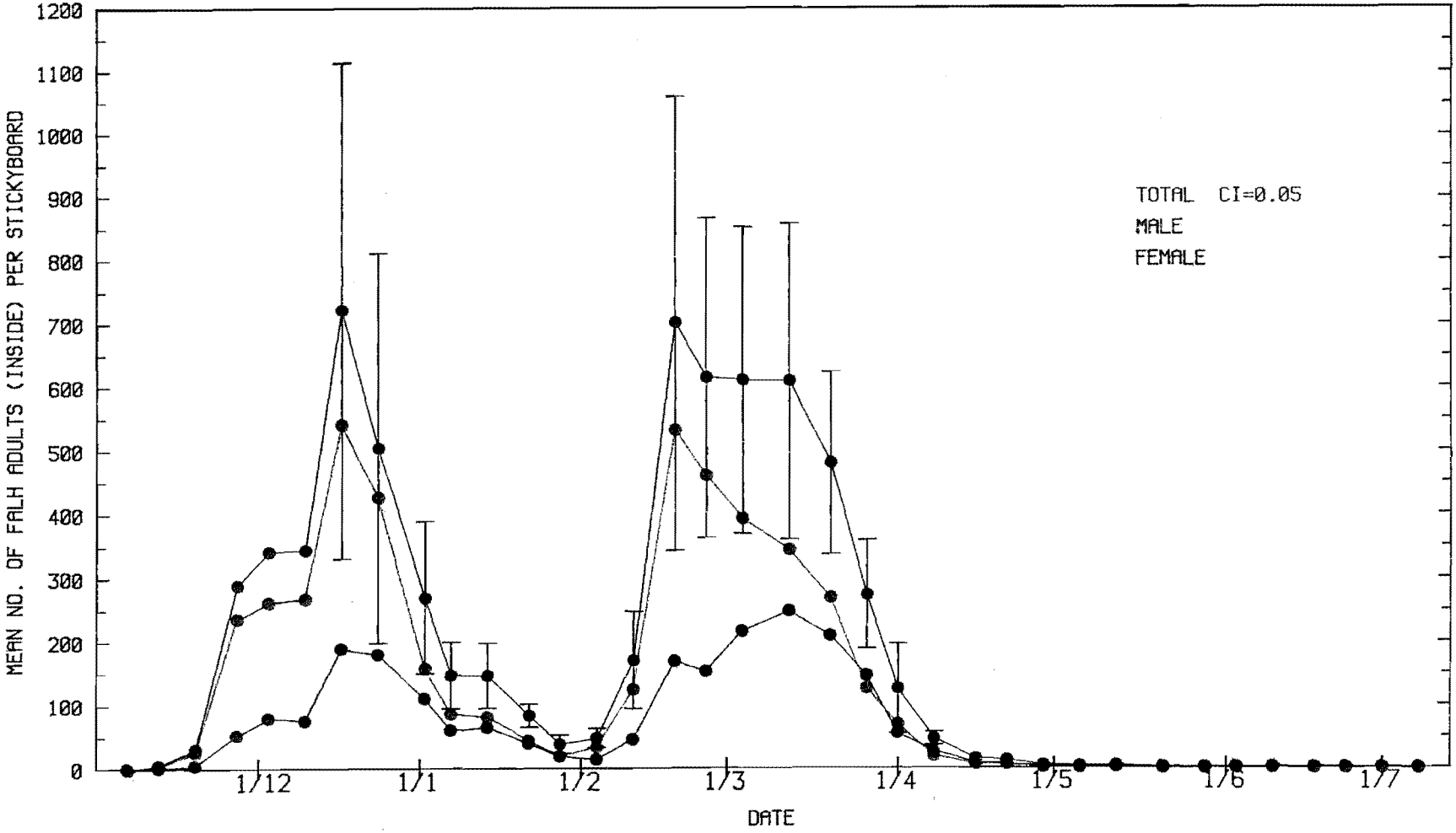
Orchard 3. Four yellow sticky boards were placed within this orchard in similar positions to the previous season, except that the 'Golden Delicious' had been removed and the two southern most boards were placed among the 'Granny Smith' (see Figure 3.3). There were no yellow sticky boards on the northern border as most of the blackberry had been removed. The four boards within the orchard had their acetate sheets changed approximately every 14 days. They were initially placed in the orchard on 11 November 1981 and sampling ceased with their removal on 30 April 1982. All species of leafhopper were counted from these traps, as well as adults of A. armatus.

(iii) Results and Discussion.

Orchard 1.

Adult sticky board catches from inside this orchard in both seasons clearly show the presence of at least two generations (see Figures 5.1 and 5.2). This was in agreement with the results obtained from summer egg and nymph counts described in the previous chapter. The small number of adults found late in the 1980-81 season (early April to June) may have been late second or possibly third generation adults. Figure 5.1 also shows the numbers of the two sexes in the 1980-81 season. Right up until mid March there were considerably more males trapped than females. This was similar for the samples in the 1981-82 season when the sexes were also differentiated (see Figure 5.2). Yellow sticky boards appear to preferentially sample males in relation to females (see Chapter 5.2). A comparison of first and peak flights on apple for the two seasons (see Table 5.1) revealed the

FIGURE 5.1: MEAN NUMBER OF FALH ADULTS PER STICKYBOARD,
INSIDE ORCHARD 1, 1980-81.



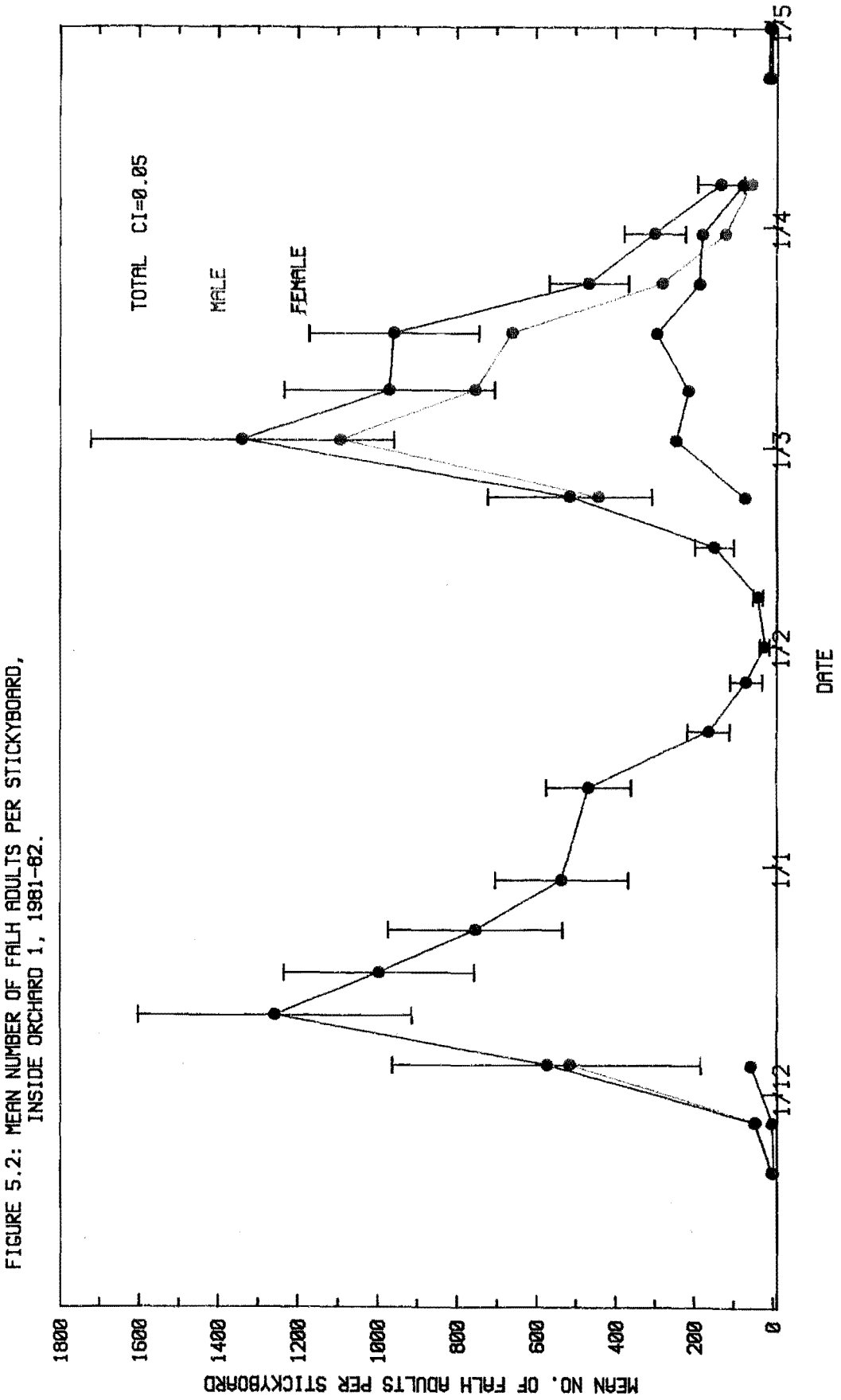


FIGURE 5.2: MEAN NUMBER OF FALH ADULTS PER STICKYBOARD, INSIDE ORCHARD 1, 1981-82.

Table 5.1: Important dates from FALH adult catches on yellow sticky boards, Orchard 1, for both seasons.

	First sample	First male	First female	First peak	Trough	Second peak	Last adult trapped	Last sample
First Season, 1980-81.								
apple	6/11	12/11	12/11	17/12	28/1	19/2	1/7	15/7
black-berry	6/11	12/11	6/11	3/12	?	4/3	28/5	1/9
Second Season, 1981-82.								
apple	17/11	17/11	26/11	11/12	1/2	2/3	30/4	30/4
black-berry	17/11	26/11	26/11	11/12	?	9/3	28/5	28/5

danger of relying on calendar measurements for establishing key times in an insect's life cycle. Adults were caught earlier in the first season (6/11/80 as opposed to 17/11/81) but peak numbers of the first generation were reached first in the second season (17/12/80 as opposed to 11/12/81). The second peak was reached first in the first season. Confidence intervals in both Figures 5.1 and 5.2 reveal the inherent sampling error using sticky boards. This was increased by differences in the development of FALH on each side of the orchard. In the second season (1981-82) this was especially apparent. Leafhopper adults were first trapped and were more numerous on the southern side of the orchard for the first three samples, probably a reflection of the warmer temperatures due to lack of shade. Later these differences disappeared. Meso-climatic differences of this sort can be important in the management of pests and may need to be measured in such a way that they are taken into consideration. If insecticide applications against FALH are to be made prior to the appearance of adults (see Chapter 2.4) then monitoring of the leafhoppers must take place where insect development is optimum.

Four other leafhopper species were found on the yellow sticky boards within the orchard in both seasons (see Figures 5.3 and 5.4), two in some numbers: R. tenerrima and Z. zealandica and two less frequently; Z. dumbletoni and E. melissae. Due to the absence of blackberry or similar Rubus spp. within this orchard, it was likely that both R. tenerrima and Z. dumbletoni moved into the orchard from the blackberry plants found in the shelter. These two species were found in greater numbers (see Figures 5.5 and 5.6) on yellow sticky boards placed outside the orchard amongst the blackberry. The number of host plants of Z. zealandica (Knight, 1976) and the numerous species of ground cover plants within this orchard (see Appendix 1) would suggest that the large numbers trapped were attributable to adults rising from the ground cover into the tree canopy. Outside the orchard a greater number of this species was caught (see Figures 5.5 and 5.6) but this was most likely due to the lower height of the sticky boards in that position. The small numbers of E. melissae (not shown in any figure) found inside and outside the orchard were probably a reflection of its more specific host plant requirements. Figures 5.3, 5.4, 5.5 and 5.6 strongly suggest that two generations of R. tenerrima were

FIGURE 5.3: MEAN NUMBER OF LEAFHOPPER ADULTS (EXCLUDING FALH) PER STICKY BOARD, INSIDE ORCHARD 1, 1980-81.

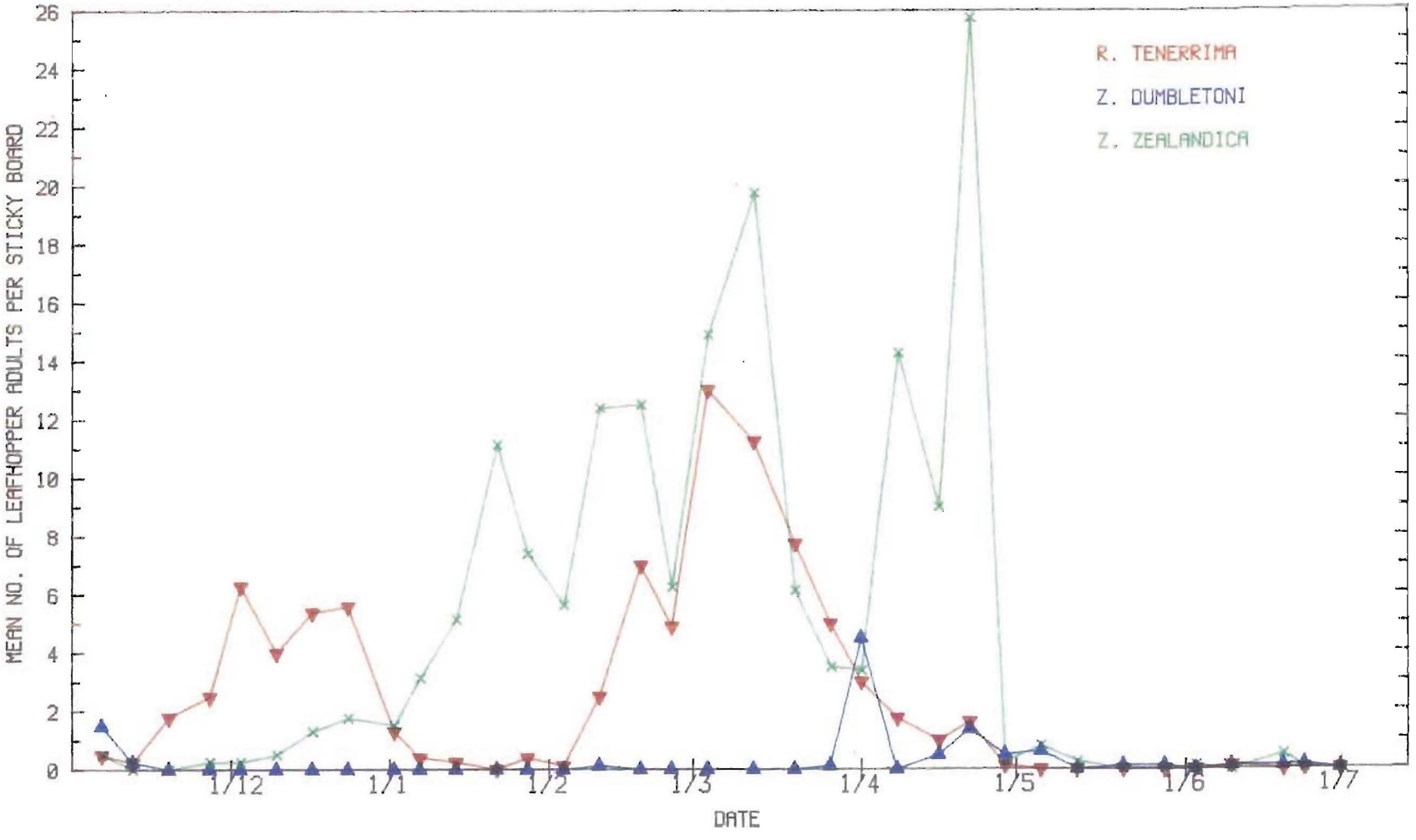


FIGURE 5.4: MEAN NUMBER OF LEAFHOPPER ADULTS (EXCLUDING FALH) PER STICKY BOARD, INSIDE ORCHARD 1, 1981-82.

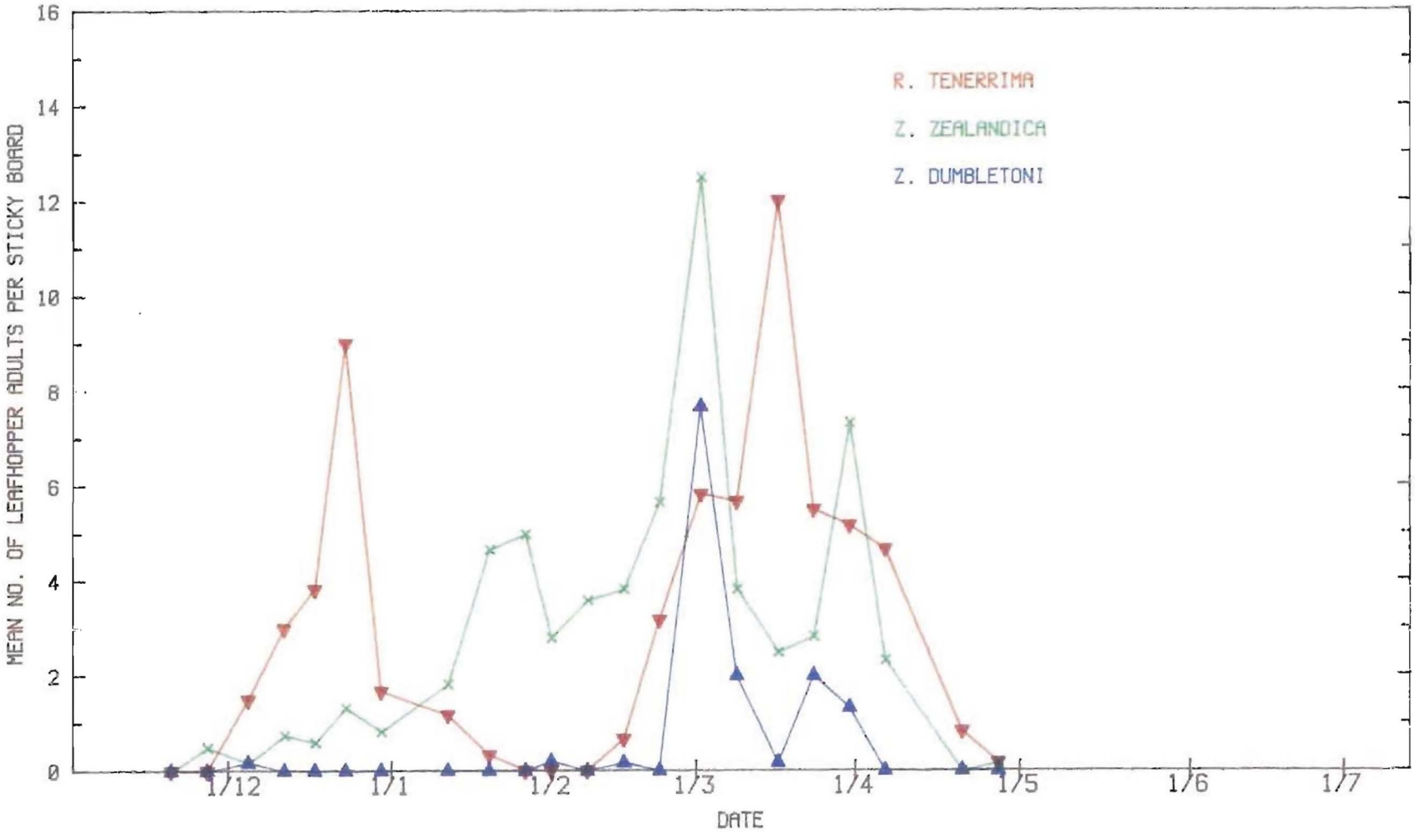


FIGURE 5.5 : MEAN NUMBER OF LEAFHOPPER ADULTS
PER STICKY BOARD,
OUTSIDE ORCHARD 1, 1980-81.

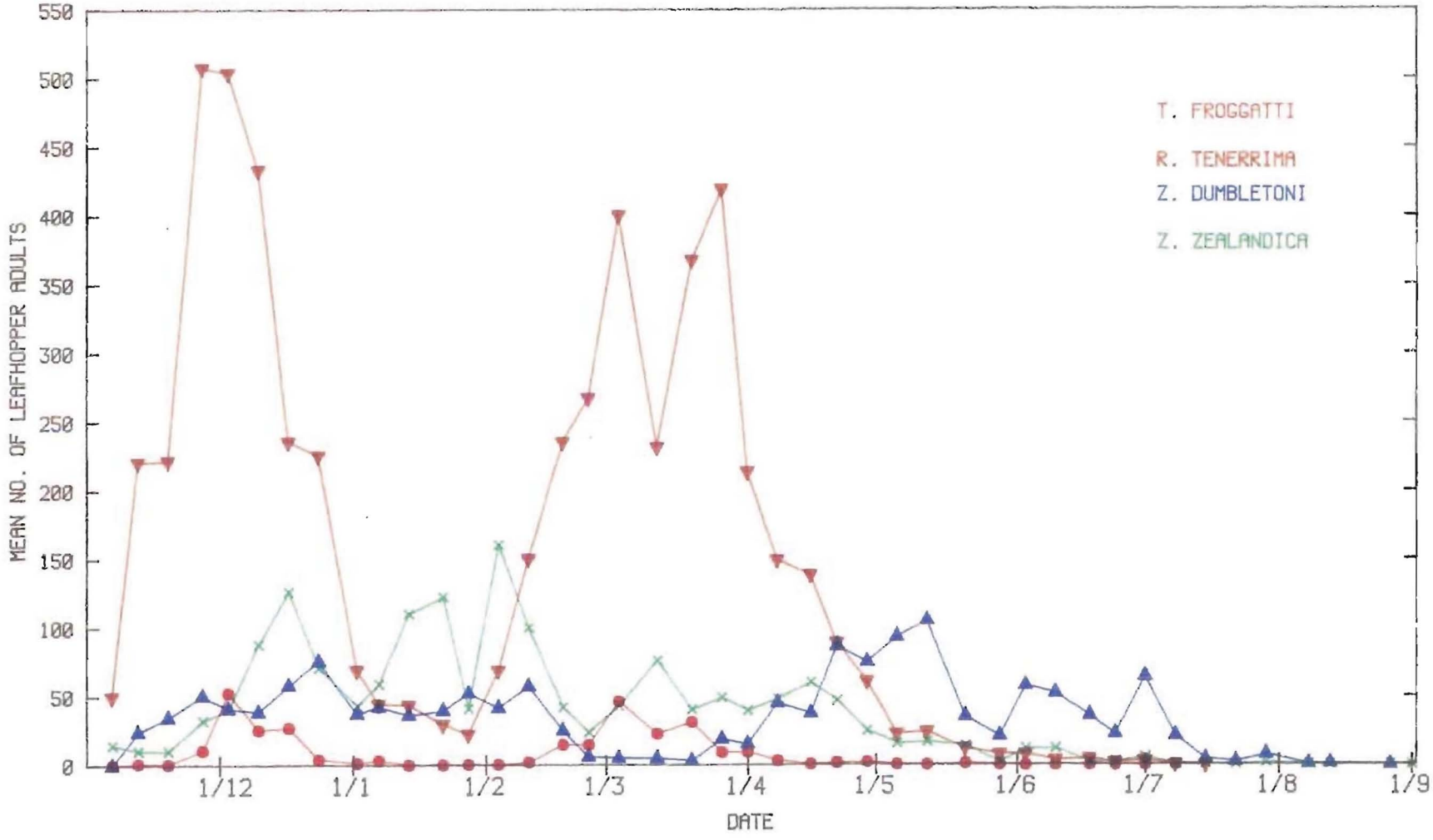
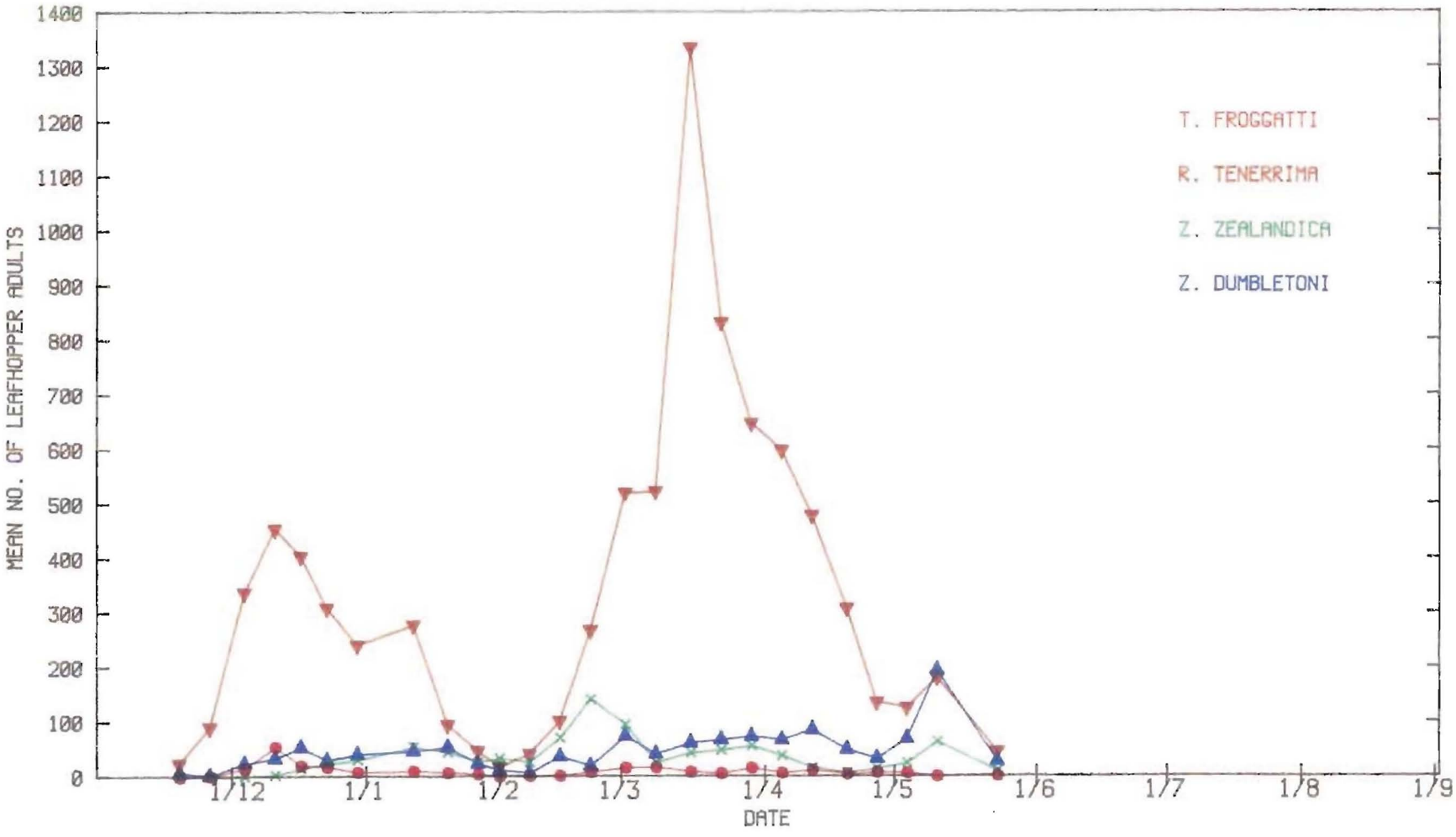


FIGURE 5.6 : MEAN NUMBER OF LEAFHOPPER ADULTS PER STICKY BOARD, OUTSIDE ORCHARD 1, 1981-82.



present over the two seasons of sampling but the irregular catches of other leafhoppers gave no clear indication as to their seasonality. These results are consistant with those of Orchard 3 (see Figures 5.11, 5.12 and 5.13). There were fewer leafhoppers (not including FALH) trapped within the orchard in the second season and this was thought to be a reflection of the slightly higher placement of sticky boards within the trees. The capture of these leafhoppers on the yellow sticky boards within the orchard presents a problem in relation to monitoring. Yellow sticky boards will only be useful for monitoring FALH adults if this species can be clearly distinguished from the other leafhoppers present. This is especially relevant when few FALH adults are present. The placement of sticky boards higher in the apple trees to reduce the number of non-arboreal leafhoppers caught will be discussed in the next section.

FALH was found in appreciable numbers on the yellow sticky boards placed outside the orchard in both seasons (see Figures 5.5 and 5.6). These individuals may have belonged to a separate population in the blackberry or may have been individuals from the population inside the orchard. Unpublished laboratory work (Teulon, unpubl.) showed that FALH nymphs could survive and adults oviposit summer eggs on blackberry, but no evidence was found as to their overwintering ability. Considering the small amount of dispersal apparent in Orchard 2 (see results, Orchard 2) and the fact that FALH adults were found on sticky boards outside the orchard a week before they were first observed inside the orchard in the first season (see Table 5.1), it would seem probable that most FALH adults trapped in the blackberry belonged to a separate population. The temporal distribution of FALH outside the orchard was broadly compatible with that found within the orchard for both seasons. From a management perspective, the presence of a FALH population in the blackberry has both advantages and disadvantages. It was clear that the population in the blackberry would never reach the proportions found on the apple trees in the orchard but it would still remain a refuge for potential migrants into the orchard. The small number migrating into the orchard is unlikely to cause economic damage but may be an important source of susceptible individuals to dilute any buildup of resistance.

Of the 1632 adult male Typhlocyba spp. sampled from traps inside (subsample) and outside (total counted) the orchard over the seven days prior to 11 December 1981, only one (caught inside the orchard) was identified as T. lethierryi. The rest were all identified as FALH. Although there is little information on T. lethierryi in the literature, what there is indicates that it has not been found in significant numbers on apple. These results suggested that the number of T. letherryi adults present in the samples did not influence the sampling of FALH.

Adults of A. armatus were found in the first sample of sticky boards in moderate numbers inside this orchard in both seasons (see Figures 5.7 and 5.8), a time when there were very few FALH adults present. The temporal synchronisation of this parasite with FALH is shown by the data in Table 5.2.

Table 5.2: Important dates from A. armatus adult catches on yellow sticky boards, Orchard 1, for both seasons on apple only.

	First sample	First adult	First peak	Trough	Second peak	Last adult trapped	Last sample
First Season, 1980-81.	6/11	6/11	14/1	11/2	11/3	28/5	28/5
Second Season, 1981-82.	19/11	19/11	27/1	22/2	9/3	30/4	30/4

In the first generation peak parasite numbers occurred approximately one month and six weeks after the peak of FALH adults in the first and second seasons respectively. This was one and four weeks respectively after peak egg counts were established in the leaf counts of each season (see Chapter 4.2). In the second generation the peak occurred approximately four weeks after the FALH peak in the first season and one week after in the second season. Although the date for oviposition of overwintering eggs was not determined for either season, the presence of the second parasite peak appeared well timed to parasitise overwintering eggs. The presence of parasites in November before many

FIGURE 5.7 MEAN NUMBER OF ANAGRUS ARMATUS ADULTS PER STICKY BOARD, INSIDE AND OUTSIDE ORCHARD 1, 1980-81.

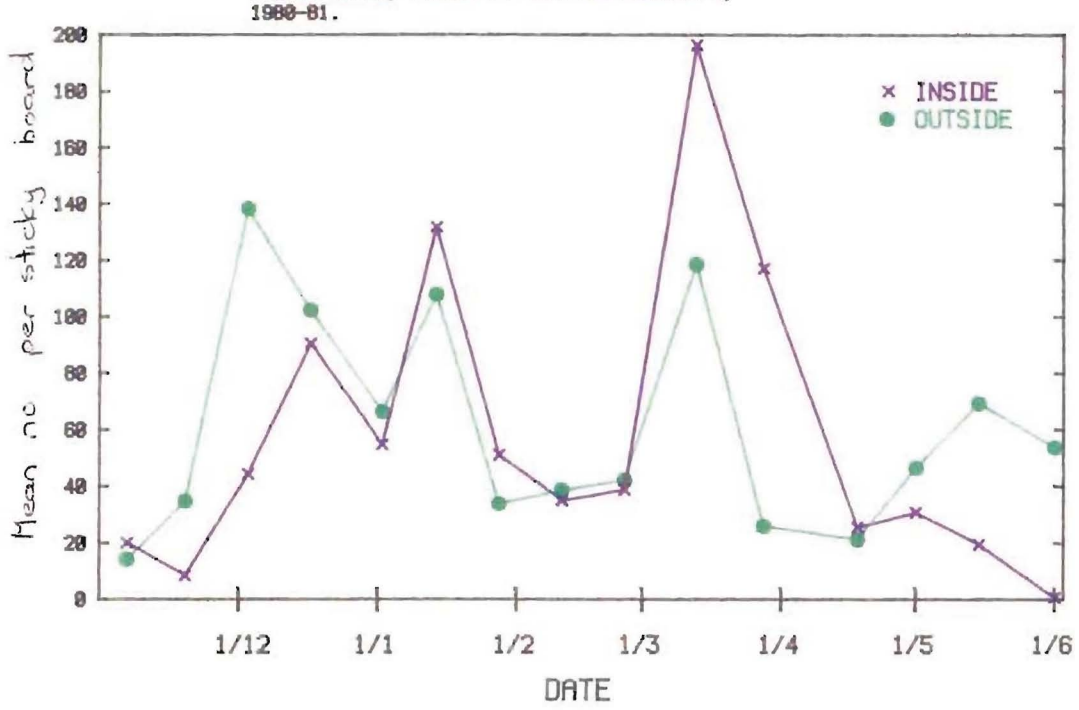
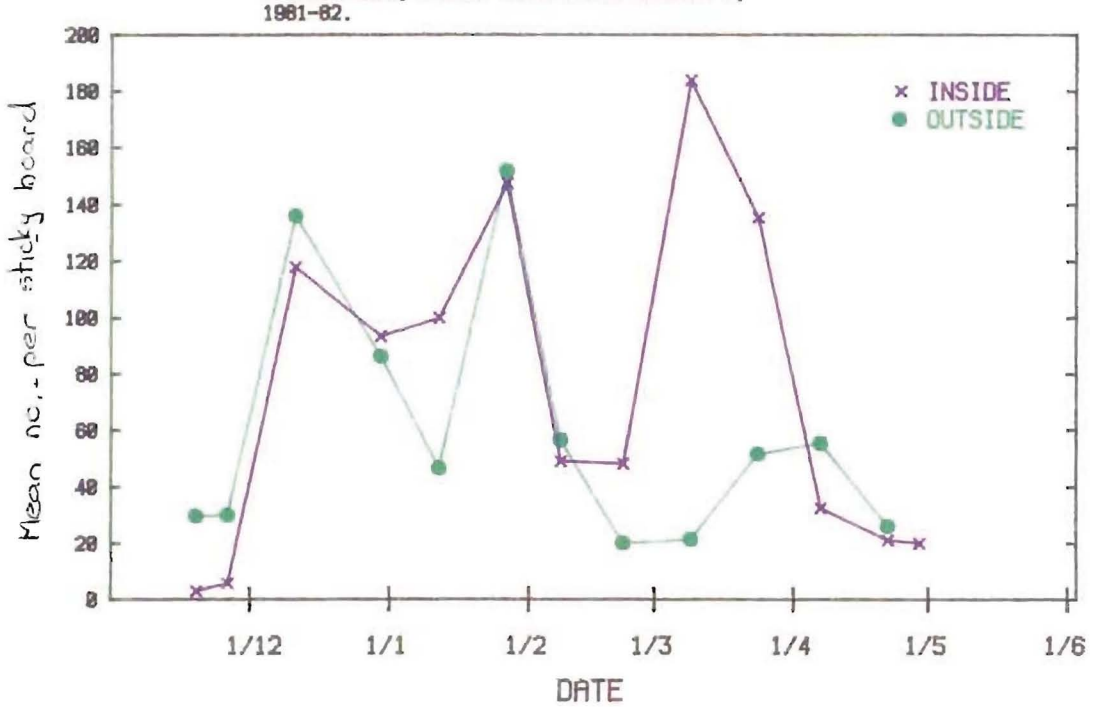


FIGURE 5.8 MEAN NUMBER OF ANAGRUS ARMATUS ADULTS PER STICKY BOARD, INSIDE AND OUTSIDE ORCHARD 1, 1981-82.



FALH adults were present on the sticky boards may imply a slight lack of temporal synchronisation but parasite adults found trapped well into May would presumably have parasitised some of the overwintering eggs laid by females found in the orchard up until early April in the first season. Therefore, the parasite, A. armatus appeared to exhibit good temporal synchronisation with its host, FALH, in both seasons. Chemical applications could be made when there are few adults parasites present in the orchard. This will be discussed further in Chapter 7.

A. armatus adults were also trapped on the sticky boards placed in the blackberry on the outside of the orchard (see Figures 5.7 and 5.8). Considering the numbers of FALH adults caught throughout both seasons on these traps and the number of parasites caught later in the season when there where even fewer FALH adults present, it was unlikely that FALH was the only host. Peck (1963) stated that A. armatus parasitised several cicadellids and so it was probable that some of the species commonly found within the blackberry were also parasitised by this mymarid. The conservation of A. armatus from other sources may prove important in the control of FALH.

Over one hundred thousand FALH adults were sampled in this orchard in the two seasons. None were observed to be parasitised by A. typhlocybae.

Orchard 2.

Figure 5.9 shows the number of FALH adults trapped on the yellow sticky boards for trees sampled inside and outside the orchard. Up until early January there were few trapped inside the orchard. The small numbers were compatible with those trapped by Tomkins (unpubl.) in this orchard during the previous season and the number caught in commercially managed orchards (see results, Orchard 3). Over the same period adults trapped on the three unmanaged trees immediately outside the orchard were numerous. During January an increase in numbers trapped inside the orchard occurred as numbers were declining outside. Figure 5.10 indicated that at this time FALH adults were evenly trapped throughout the orchard, suggesting that most of the adults were part of a population already established in the orchard. If a large proportion of those trapped at this time had come from elsewhere, it would be expected that the number trapped would be unevenly distributed

FIGURE 5.9: MEAN NUMBER OF FALH ADULTS PER STICKYBOARD, INSIDE AND OUTSIDE, ORCHARD 2, 1980-81.

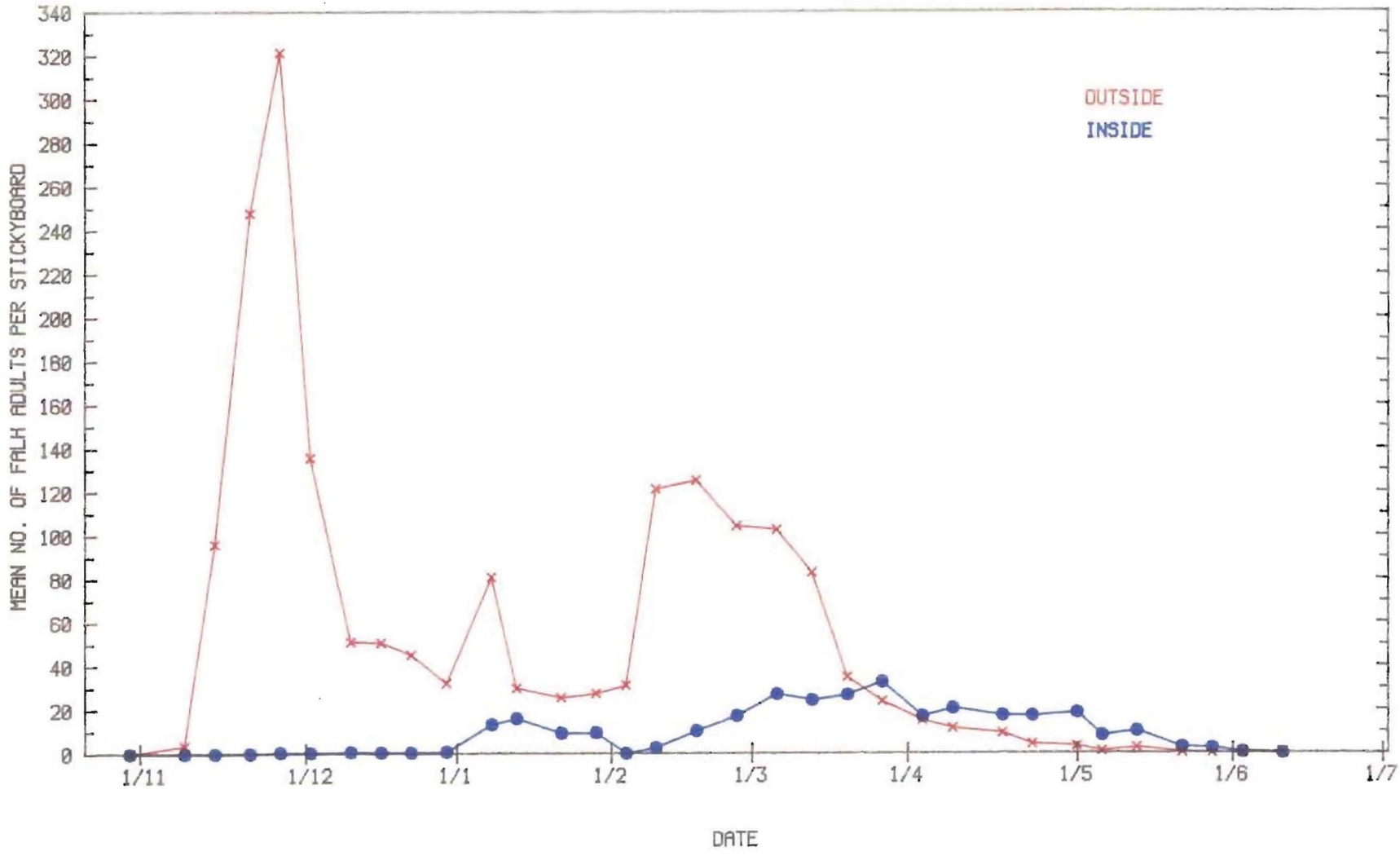
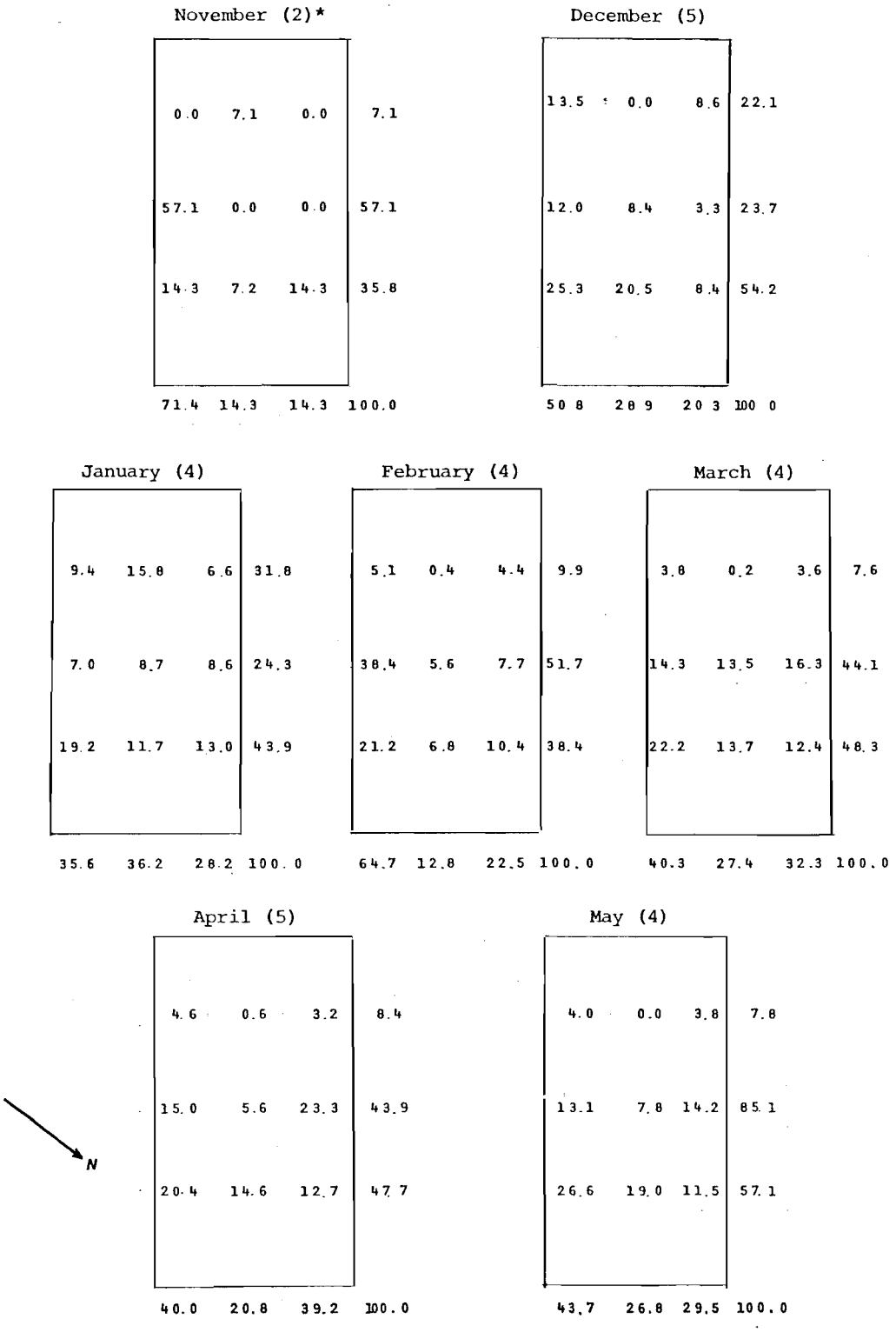


Figure 5.10: Monthly trap of FALH adults (percentage) per sticky board, inside orchard 2, 1980-81, showing position of trap within the orchard.



* number of sample dates per month.

throughout the orchard, with the greatest catches being closest to the point of entry. In early February FALH adult numbers trapped on the apple trees outside Orchard 2 increased for a short time then decreased. The increase was probably a reflection of the development of second generation adults. Premature leaf fall influenced by strong southerly winds, lack of shelter, and management were likely factors that brought about the early decrease in the adults trapped. Inside the orchard there were few adult leafhoppers in early February probably because of the corresponding delay in the first generation. After this time the number of leafhopper adults trapped inside the orchard increased and in late March surpassed the number trapped on the trees outside the orchard. Figure 5.10 shows that the proportion of FALH adults trapped over this time was not even throughout the whole orchard. A larger proportion were trapped on the northern most traps and in general more were caught on the traps closest to the eastern boundary. The most likely interpretation for these results is that as the habitat outside the orchard became deficient, the leafhoppers left and searched for new hosts. The prevailing north-east wind (Cherry, pers. comm.) and the proximity of the trees on the eastern side of the orchard meant that most leafhoppers migrated to positions where they were trapped in most abundance within the orchard. In order to do this they had to pass through or over a row of poplar shelter. It appeared that within the orchard the second generation was made up of newly migrated adults as well as those developed from eggs laid within the orchard by first generation females. Thus it appeared that FALH adults were reluctant to migrate until the habitat became unsuitable.

These results indicate the ability of FALH populations to build up in an uncontrolled environment. Tomkins (unpubl.) found a maximum of approximately 0.5 adults per trap per week (in December) in the previous season (1979-80). The numbers were much lower than this in the second generation. In the first generation of the 1980-81 season when control measures were virtually non-existent a maximum of approximately 16 adults per trap per week were caught, a considerable increase on the numbers of the first generation of the previous season. In the second generation there was a further increase but this was influenced by migration. This high rate of increase over one season needs to be considered in the light of possible resistance and the

application of fewer insecticides to apple orchards. The presence of a large leafhopper reservoir close to orchards would appear to be inadvisable if leafhopper control were to be maximised where insecticide applications are low. It may therefore be important to remove such reservoirs. Smaller reservoirs, such as blackberry, may be useful for reasons previously discussed.

Orchard 3. In comparison with the other two orchards sampled there were very few FALH adults trapped in Orchard 3 in both seasons (see Figures 5.11 and 5.12). This indicated that present pesticide applications aimed at 'key pests' were very successful in controlling FALH populations as well. The number of FALH adults trapped was consistent with those caught by Tomkins (unpubl.) in the 1979-80 season in several commercial orchards in the Canterbury region.

The presence of other leafhoppers inside Orchard 3 is also described in Figures 5.11 and 5.12. These figures were comparable with those of other leafhoppers found inside Orchard 1 (see Figures 5.1 and 5.2) with some slight exceptions. There were overall, slightly fewer leafhoppers in Orchard 3, probably due to pesticide spray drift from the trees. The similarity in numbers between both orchards would suggest that none of these species inhabited the apple trees. If they did, it would be expected that the number of leafhoppers (beside FALH) found in Orchard 3 would be much lower than in Orchard 1, due to direct pesticide applications within the tree. Unpublished data (Teulon, unpubl.) strongly suggested that adults of R. tenerrima would not feed or oviposit on apple leaves.

These results show the problem of other leafhoppers caught on the sticky boards when the FALH population was low. Without careful examination of the boards FALH adults could easily be missed amonst the large number of other leafhoppers.

In the two traps outside Orchard 3 in the first season there was a predominance of R. tenerrima caught over any other species (see Figure 5.13). This was a reflection of the position of the traps (placed amongst the blackberry) and was similar to the leafhopper adults caught outside Orchard 1 (see Figures 5.5 and 5.6). Although only 20 adults of FALH were caught on the outside traps over the season, this was more than caught in the traps within the orchard in the same season.

FIGURE 5.11: MEAN NUMBER OF LEAFHOPPER ADULTS
PER STICKY BOARD,
INSIDE ORCHARD 3, 1980-81.

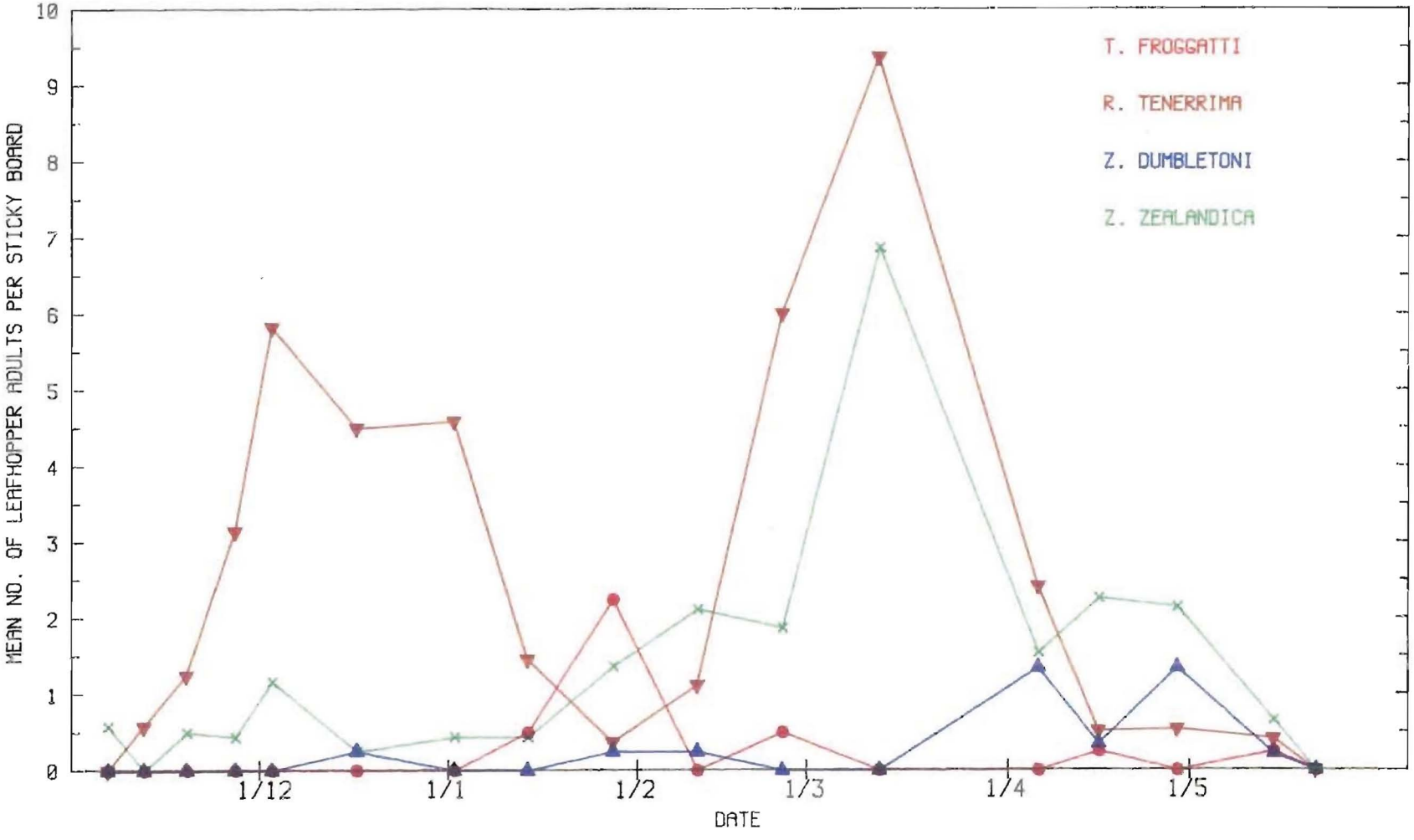


FIGURE 5.12: MEAN NUMBER OF LEAFHOPPER ADULTS
PER STICKY BOARD,
INSIDE ORCHARD 3, 1981-82.

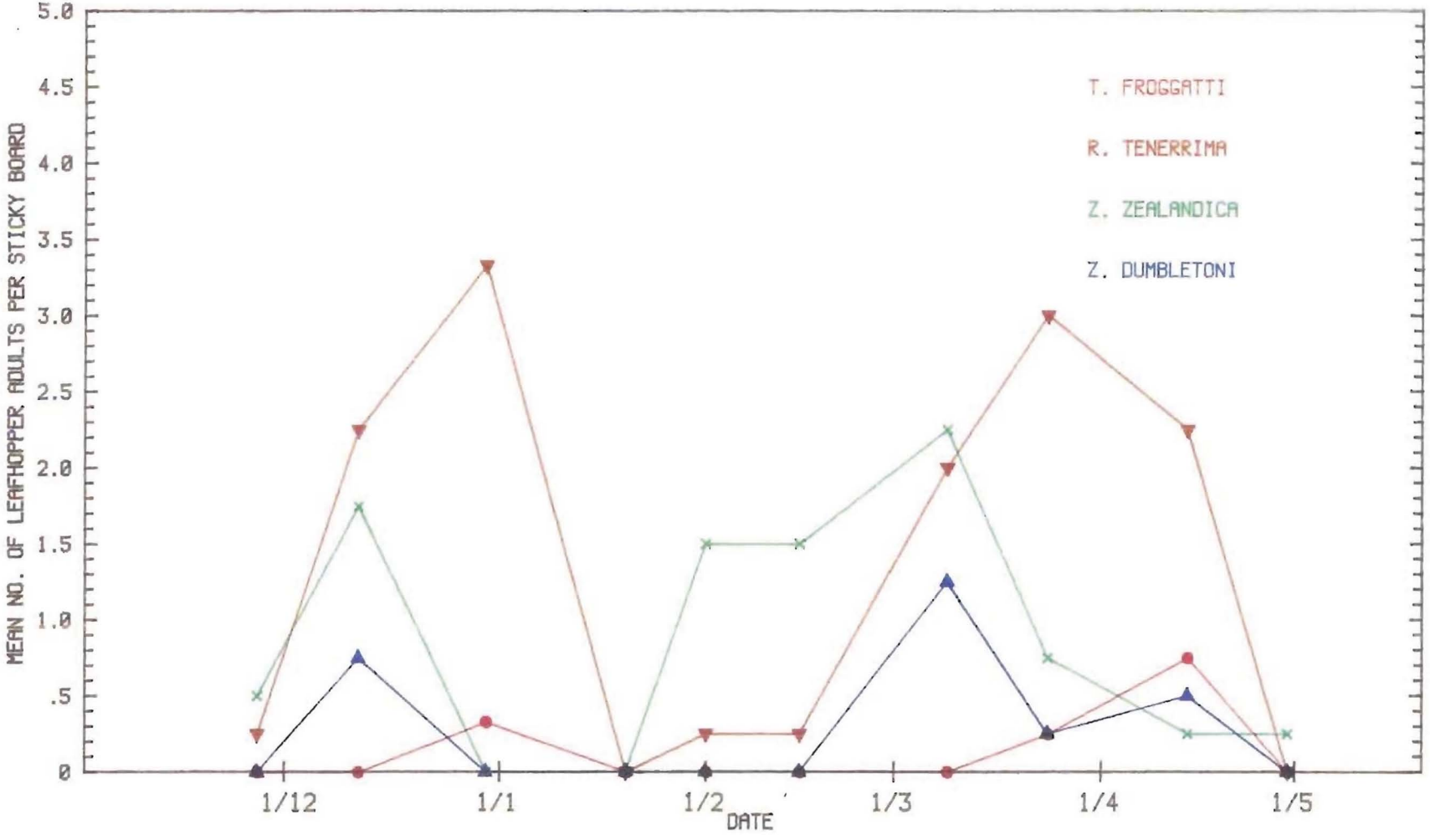
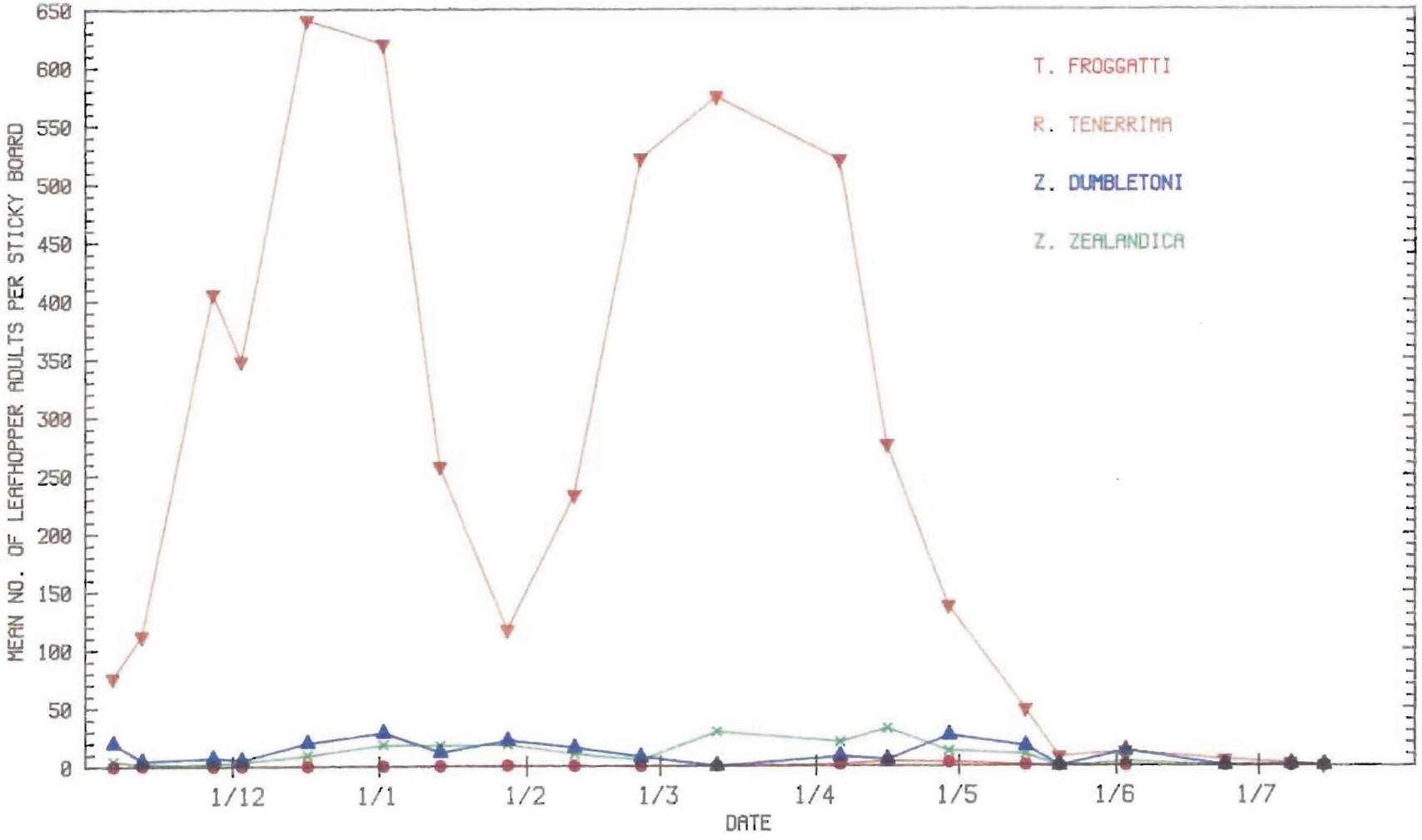


FIGURE 5.13: MEAN NUMBER OF LEAFHOPPER ADULTS PER STICKY BOARD, OUTSIDE ORCHARD 3, 1980-81.



Trapping results of R. tenerrima and Z. dumbletoni inside the orchard consistently showed greater numbers of these two species caught in the northern traps inside the orchard, closest to the blackberry. The number of replicates and nature of sticky boards precluded any statistical analysis of this data but it seemed likely that many of these insects were present because of the proximity of the blackberry. Therefore, removal of host plants would help to reduce the number of other species on the sticky boards but as has already been mentioned, these host plants may be important as a refuge for susceptible FALH individuals and as a source of A. armatus. Three individuals of E. melissae in total were found on the traps inside the orchard in both seasons and five on the traps outside the orchard in the first season.

Adults of A. armatus were found in small numbers inside this orchard (see Figures 5.14 and 5.15) and showed little change in numbers with time. Thus the spray programme was effective in reducing the number of parasites present. This may have been directly, by killing the parasites through lethal effects, or indirectly, by reducing the number of host leafhoppers present. It was probable that many of those parasites were not parasitising FALH alone but other species of leafhopper within the orchard. There were two reasons for suggesting this: first, the small numbers of FALH adults found within the orchard (see Figures 5.11 and 5.12); secondly, in the first season a large proportion (80%) of the parasites were trapped on the northern sticky boards, presumably influenced by the large number of parasites found in the blackberry (see Figure 5.14). The presence of alternative hosts for A. armatus in apple orchards would certainly appear to be an advantage in the control of FALH. In this case blackberry seemed a suitable habitat in which A. armatus could parasitise other leafhoppers but this plant is also a significant host for the 'key pest', Epiphyas postvittana, in apple orchards (Baker, 1968) and is also considered noxious in this country. In general there were fewer leafhopper and parasite adults in the second season. This may have been attributable to the removal of the ground cover and blackberry on the northern border thus reducing the amount of alternative hosts present.

FIGURE 5.14 MEAN NUMBER OF ANAGRUS ARMATUS ADULTS PER STICKY BOARD, INSIDE AND OUTSIDE ORCHARD 3, 1980-81.

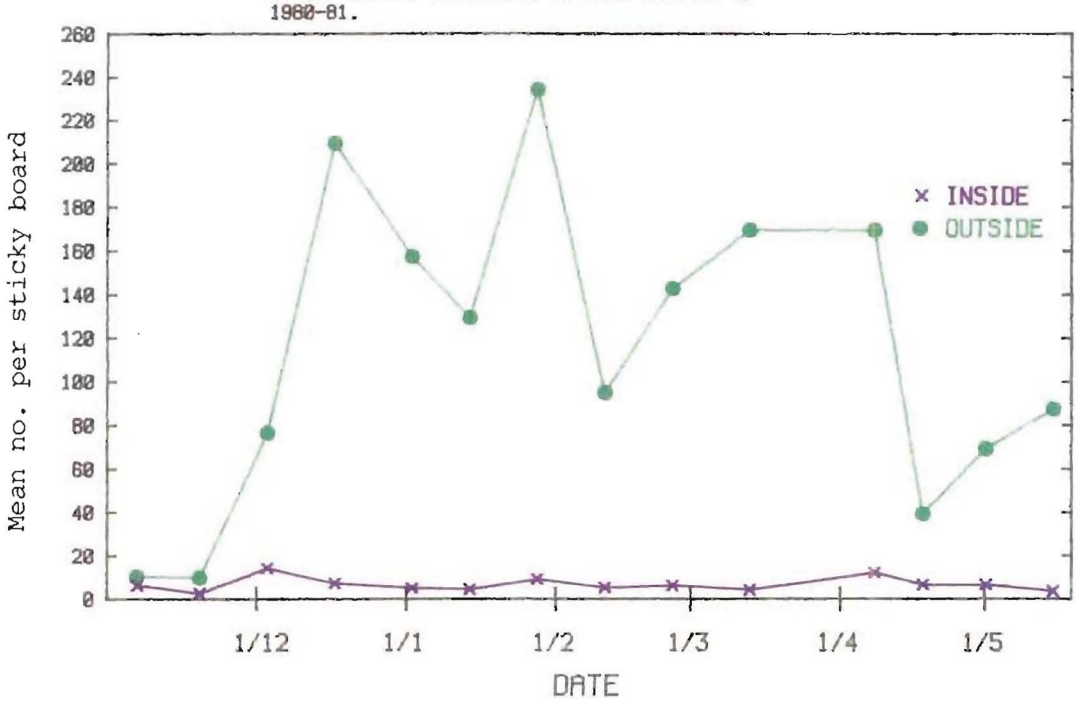
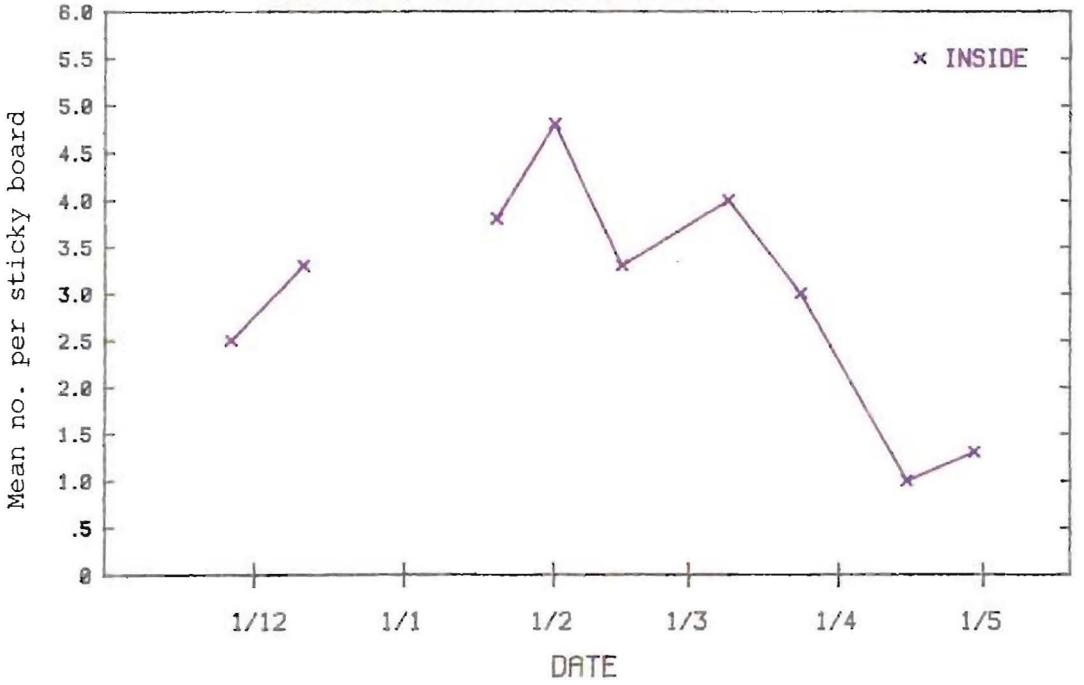


FIGURE 5.15 MEAN NUMBER OF ANAGRUS ARMATUS ADULTS PER STICKY BOARD, INSIDE ORCHARD 3, 1981-82.



(iv) Summary.

During the two seasons (1980-81 and 1981-82) of sampling in an unmanaged apple orchard (Orchard 1), the sticky board catch of FALH adults showed two distinct peaks in numbers strongly suggesting the presence of at least two generations. In the second season males were initially caught on the boards before females and in both seasons there was a large predominance of males right through until near the end of the season. Outside the orchard in the blackberry, a similar distribution of FALH numbers over time was found in sticky board catches. The FALH trapped in the blackberry were probably a separate population to those within the orchard and may provide a suitable small reservoir for susceptible individuals to dilute resistant genes in an insecticide controlled environment. A subsample of adult male Typhplocyba spp., carried out when peak numbers were recorded on the sticky board traps, in the first generation of the second season in Orchard 1, revealed only one individual of T. lethierryi out of a total of 1632 leafhoppers counted. The rest were all FALH. It was therefore assumed that the numbers of T. lethierryi would not influence the samples of FALH at other times. Migration of FALH adults was investigated from trees of high infestation into an orchard of low infestation (Orchard 2). It appeared that migration was mainly influenced by the condition of the food plants. Leafhoppers did not appear to leave the highly infested trees until they became unsuitable. The prevailing wind probably affected the speed of migration. The ability of FALH numbers to increase quickly was also shown by this study and it was suggested that the removal of large reservoirs of FALH close to orchards would be important to reduce infestation where application of insecticides is reduced. Sampling FALH adults by yellow sticky boards in a commercial orchard (Orchard 3) showed that present chemical control measures are adequate to control the increase of FALH numbers.

The egg parasite of FALH, A. armatus, had a roughly bimodal distribution of numbers over time within the abandoned orchard (Orchard 1). This gave it a good temporal synchronisation with FALH. The parasite was found in large numbers outside Orchard's 1 and 3, in the presence of other leafhoppers, where its temporal distribution appeared less defined. This suggested that A. armatus parasitised other

leafhoppers besides FALH. In the commercial orchard (Orchard 3) there were few adult parasites caught. Application of chemicals at the appropriate time would lead to conservation of these parasites and the presence of other suitable hosts would encourage them in the orchard.

In Orchards 1 and 3 (they were not counted for Orchard 2) there were at least four other species of leafhopper besides FALH. Their presence seemed to be the result of their host plants being within or close to the edge of the orchard. The presence of these species will complicate monitoring of FALH.

In Orchard 1 where over one hundred thousand FALH adults were sampled in the two seasons none were observed to be parasitised by A. typhlocybae.

5.2 Some Properties of Sticky Board Sampling.

(i) Introduction.

During the sampling of adult leafhoppers by yellow sticky boards discussed in the previous section a number of questions arose as to the accuracy and adequacy of such a method. In this section several experiments were designed to investigate various aspects of this sampling method and test it against other methods of which more is known, or work in such a way that they may give some insight into the accuracy of using sticky boards.

Experiments were established to test the reflective nature of the yellow sticky boards and to compare their use with the 'D-Vac vacuum insect sampling machine' (D-Vac Co, Riverside, California) and the 'Johnson and Taylor insect suction trap' (Burkard Manufacturing Co Ltd. Rickmansworth, England).

The D-Vac (back pack model) consists of a fine mesh net held open inside a fibreglass cone, the narrow end of which is attached by a length of flexible hosing to a suction unit operated by a two-stroke motor. The motor and suction unit are carried on the back while the hand-held cone is moved through the foliage to collect insects. This device is known as a relative method of sampling (Metcalf and

Luckman, 1975) as it captures a more or less consistent, if unknown, proportion of the insects present.

The Johnson and Taylor suction trap, in comparison, is known as an absolute method of sampling (Southwood, 1978) as the number of insects per unit of air can be calculated. This device can also sample insects over a continuous time period, unlike the D-Vac which samples a discrete time. Southwood (1978) gave a description of the makeup and use of a Johnson and Taylor suction trap.

Sleeve cages were placed on trees within the orchard to determine if the sticky boards were recording the period of initial flight for the adults of both FALH and A. armatus.

Throughout the sampling programme for both seasons, leafhoppers other than FALH, were trapped on the yellow sticky boards. These species' main host plants were in either the ground cover of the orchard or along the orchard border. It was thought, and evidence in the previous section supported this, that the further the sticky boards were from the ground the fewer the number of non-arboreal leafhoppers would be caught. Therefore the influence of sticky board placement in relation to height was investigated.

(ii) Materials and Methods.

A. Reflectance Measurement.

Four boards, that had been used in the field sampling of adult leafhoppers and that had a uniform coating of yellow colour, were selected to determine their spectral reflectance. From each board three small rectangles (approximately 40 x 40 mm) were cut from the centre of the board. These rectangles were then treated in the following way: to one, the rectangle was covered with Tack-trap; to the second, the rectangle was covered with Tack-trap, then an acetate rectangle of the same surface area was placed on this which was also covered in Tack-trap. The third rectangle was left clean.

The spectral reflectance of each yellow rectangle was measured as a percentage of the reflectance from a white barium sulphate (Eastman White) standard in a Zeiss PMQ3 spectrophetometer between 380 and 770

nanometres. The wavelengths between 500-600 nm are a major component of the reflected light from green leaves (Vaishampayan et al., 1975; Prokopy et al., 1975) and apparently coincide with the maximum positive stimulus for leafhoppers (Alverson et al., 1977). Prokopy (1972) suggested that fruit flies were attracted to yellow as it constituted a 'supernormal' foliage-type stimulus eliciting food seeking and/or host plant seeking behaviour.

B. Comparison with Other Sampling Methods.

D-Vac Sampling Machine. On 26 March 1981, eight yellow sticky boards were placed within Orchard 1, one on each tree randomly selected from within the eight blocks shown in Figure 3.1. That was: four trees from the northern side (N1, N2, N3, N4) and four trees from the southern side (S1, S2, S3, S4). Those trees that already had sticky boards from other experiments were not considered for this sample. The boards were positioned and secured in the same way as those described for the first season (1980-81) in the previous section (Chapter 5.1). Six days later (1 April 1981) the acetate sheets were removed from the boards and placed on lined computer sheets as described in Chapter 5.1. The boards were removed from the trees and both the boards and acetate sheets were taken back to the laboratory where the number of leafhoppers caught on the acetate sheets were counted. The sexes of FALH were differentiated. On the same date (1 April 1981) a D-Vac sampling machine was used to sample the same trees. This was achieved by walking around the tree twice, brushing the mouth of the sampler across the leaves on the periphery of the canopy. The first circle of the tree was made at a height just above the centre of the sticky board and the second just below it so that an area of two D-Vac mouth widths (about 0.70 m) was sampled around the tree at a height equivalent to the sticky boards. After sampling each tree, the D-Vac collecting bag was emptied into a labelled plastic bag which was then sealed with a rubber band so that no leafhoppers could escape. In the laboratory the leafhoppers in the bags were placed in alcohol. Leafhoppers were identified to species under a binocular microscope and the sexes differentiated for FALH. The sticky boards remained in the orchard for approximately six days but the D-Vac sample was almost instantaneous. Nevertheless, the sample was taken at a time in the season when the ratio of male/female appeared relatively even and stable (see

Figure 5.1). Chi-square testing for the independence of sampling method to FALH numbers of each sex caught were carried out on each tree individually.

Johnson and Taylor Suction Trap. In a private property in close proximity to Lincoln College a single yellow sticky board was placed halfway between the trunk and outside canopy of a Ballarat apple tree at approximately 1.75 m above the ground. On the opposite side of the tree a 9 inch (229 mm) Johnson and Taylor suction trap was placed in a similar position. The suction fan was run on the slowest of the three speeds available. Both sampling devices were positioned on 22 February 1982. Each day at approximately the same time the suction trap catch was removed. The acetate sheets of the yellow sticky boards were changed (as described previously, see Chapter 5.1) every week up until 3 May 1982. Continuous trapping by both the suction trap and the sticky board was therefore measured over a period of 10 weeks. For both sampling methods the sexes of FALH were counted. Adults from the suction trap catches were placed in alcohol. Although the adults of A. armatus were collected by both methods, the numbers caught in the suction trap were an underestimate as the fine slits in the collecting tube were not small enough to preclude these parasites from escaping.

To compare the accuracy of the yellow sticky board the weekly FALH catches were regressed against the accumulated (for each week) daily suction trap FALH catches.

Sleeve Cages. From each block (see Figure 3.1) of the second 'Sturmer' row on the northern side of Orchard 1, one tree was selected. Two sleeve cages (approximately 150 x 150 mm) were placed on each tree, one in the lower section (below 2 m) and one in the upper section (above 2 m). Initially an attempt was made to place the cages on twigs that had the previous season's growth represented. Later when leaves appeared an attempt was made to cover both leaves and twigs (of the age previously mentioned) by the cages. The sleeve cages were made from terylene in a cylindrical manner so that they could completely enclose part of the tree. They were fastened at both ends. On each sample date the twig below the sleeve cage was cut with a pair of secateurs, labelled and removed to the laboratory where it was placed in a freezer at -12° C for at least 24 hours. This killed any insects within the

sleeve so that the contents could then be examined under a binocular microscope. FALH nymphs and adults were counted and noted as were adults of A. armatus.

The first sleeve cages were placed in Orchard 1 on 27 August 1981, collected and replaced approximately every seven days until 19 January 1982.

C. Influence of Height on Sticky Board Catch.

In the first generation of the 1981-82 season an experiment was designed to ascertain the influence of height on leafhopper trapping. This coincided with the maximum trapping of FALH adults for this generation (see Chapter 5.1). On the 14 December 1981 six 'Sturmer' apple trees were randomly selected from the northern outside row of Orchard 1 (see Figure 3.1). Trees that already had sticky boards were not considered for this sample. On each of these trees, three yellow sticky boards were placed at heights of 0.9, 1.5 and 2.1 m, in a position halfway between the middle of the tree and the outer canopy. These sticky boards were left in the orchard for nine days when on 23 December 1981 the acetate sheets and boards were removed from the orchard. In the laboratory the acetate sheets were examined in the same way as usual (see Chapter 5.1): the leafhoppers were counted but sexes only differentiated for FALH.

In the second generation this experiment was repeated, also at a time when FALH numbers were high but an extra yellow sticky board was placed at 2.7 m. On this occasion the boards were left in the orchard for a period of seven days in late February 1982. Otherwise the sampling proceeded as in the previous generation.

The data was analysed using the method described by McNemar (1969) for a repeat-measure design.

(iii) Results and Discussion.

A. Reflectance Measurement.

The mean spectral reflectance curves for the three yellow boards are shown in Figure 5.16 for the wavelengths between 380 and 770 nm. The variance at each point was very small and is therefore not shown in the figure. Each treatment initially showed a low reflectance up until approximately 480 nm where the curve rose steeply until it began levelling off at approximately 530 nm. From 600 nm through to 770 nm the curve was almost linear. The spectral reflectance of the bare yellow board was always highest throughout the wavelengths measured. Up until 500 nm the yellow board with acetate and Tack-trap had a higher percentage reflectance than that with only Tack-trap. After this the yellow board with acetate and Tack-trap had the lowest spectral reflectance of the three boards measured. The percentage reflectance of the treatments above 510 nm responded in a way that would be expected by a clear covering of a surface (Judd and Gibson, 1936); the percentage reflectance decreased with more covering. Why there was an intermediate reflectance by the board with acetate sheet below 500 nm was unknown. These results coincide with those of Ferro and Suchak (1980) who found that Tack-trap consistently reduced the percentage reflectance for 'federal safety yellow'.

The addition of acetate sheets to the sampling process proved to be very successful in saving sampling time, costs and improving storage of the trapped insects and these results show that little reflectance was lost for this gain.

B. Comparison with Other Sampling Methods.

D-Vac Sampling Machine. Contingency tables (2x2) for the Chi-square analysis comparing sample method and FALH sex for each tree are found in Appendix 6. The number of each sex caught was not independent of the sampling method on four occasions (trees N3, N4, S2, S4) at $p < 0.005$, on one occasion (tree S3) at $p < 0.01$ and on one occasion (tree N1) at $p < 0.1$. The fact that two of the sample trees did not show independence in the sampling method was an indication of the variability within the orchard. Table 5.3 shows the male/female ratio for each tree and each sampling method.

FIGURE 5.16 MEAN SPECTRAL REFLECTANCE CURVES
FOR YELLOW STICKY BOARDS.

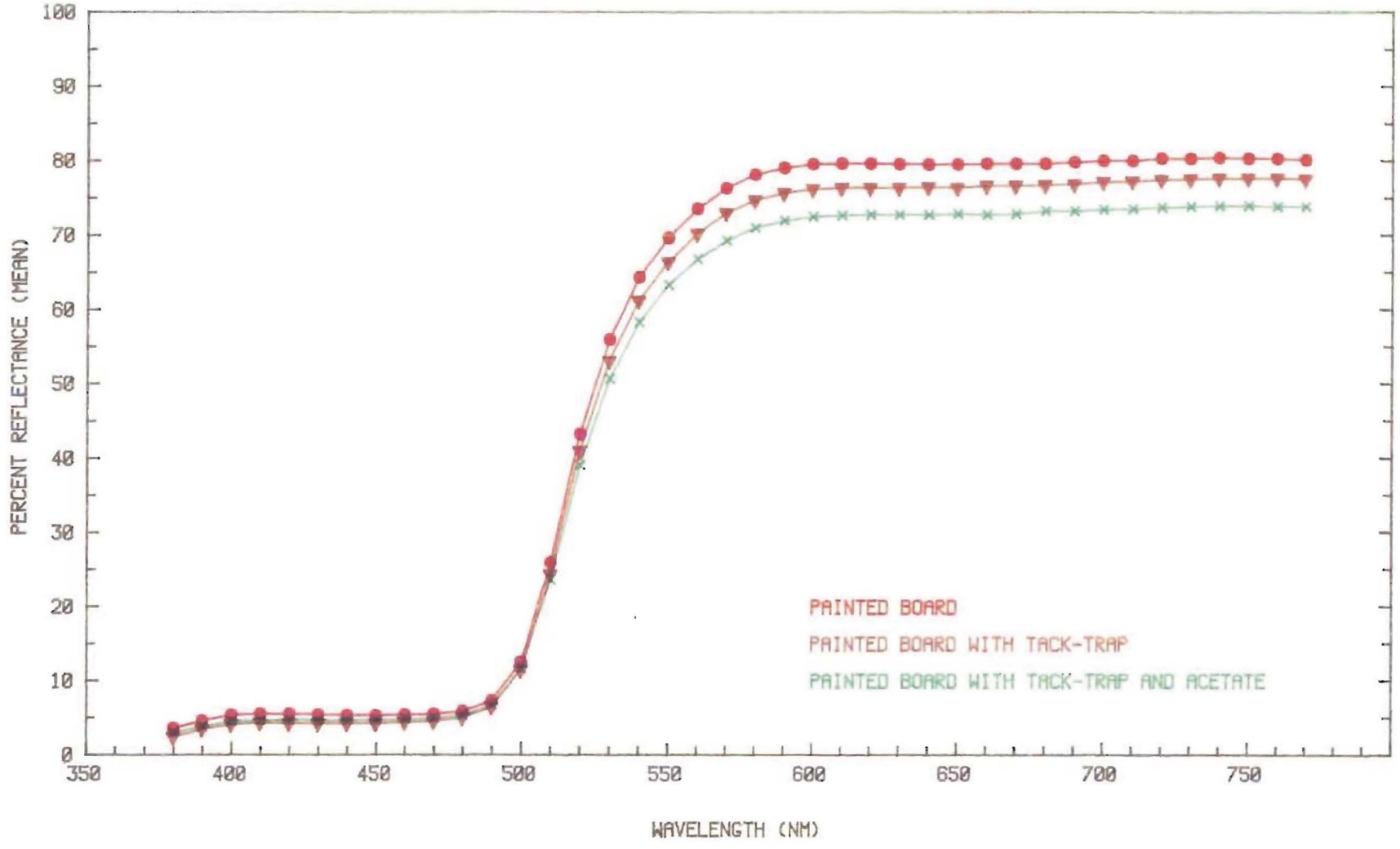


Table 5.3: Comparative catches of the sticky boards and D-Vac suction sampler showing male/female ratios of FALH adults.

TREE		N1	N2	N3	N4	S1	S2	S3	S4
FALH (n)	Sticky board	74	76	117	79	78	98	129	172
	D-Vac	21	8	33	12	36	7	49	45
Others (n)	Sticky board	8	13	6	9	6	5	7	3
	D-Vac	1	3	4	0	0	0	1	1
FALH (ratio)	Sticky board	0.54	0.63	1.00	1.63	0.62	1.03	1.97	2.44
	D-Vac	0.23	0.38	0.24	0.23	0.33	0.00	0.17	0.22

These results show that there is obviously some difference in the ratio of sexes caught by the different methods. With the sticky boards the ratio was always above 0.5 but with the D-Vac the ratio was always below 0.38. A closer look at the contingency tables shows that a large contribution to the Chi-square value came from the cell of D-Vac male samples. In six of the eight trees (N1, N2, N3, N4, S1, S2) this cell contributed the greatest amount and in the other two trees this cell contributed the second largest amount. In every case the expected value was higher than the observed value suggesting that males were under sampled by the D-Vac. In the two trees where this cell did not contribute the most to the Chi-square value the major contribution came from the D-Vac female cell. On these occasions the expected value was much smaller than the observed value suggesting that females were oversampled by this method. The D-Vac suction sampler therefore appeared to undersample males or conversely oversample females. Alternatively, it could be stated that the sticky boards were oversampling males and undersampling females. The latter was the more likely explanation as the sticky boards had more variables that influenced the sample. The D-Vac sampler did not rely on attraction and the strong suction probably collected most of the insects present. Therefore, these results indicated that the sticky boards differentially sampled the sexes of FALH in comparison with the D-Vac sampling machine. Adult males appeared to be preferentially sampled in

relation to adult females. There may be several reasons for this. First, adult males may be more attracted to the spectral reflectance of yellow than females or alternatively females may be postively repulsed. Secondly, males may be more active flyers than females and therefore have a greater propensity to be caught on the sticky boards. Thirdly, some property of Tack-trap may be responsible for attraction/repulsion of either sex. The manufacturers of Tack-trap claim that it has no repellent or attractive properties and none have been reported in the literature.

When comparing the trap catches of FALH adults on transparent and yellow sticky boards on apple trees, Tomkins (unpubl.) found that over a period of time more males were caught on the yellow sticky boards than transparent boards but that approximately the same number of females were caught on each board. More males than females were caught on both types of board. These results suggest that the difference in attractiveness to the yellow board is the primary reason for differing sex ratios of the yellow sticky boards and the D-Vac. When collecting FALH adults from apple trees with an aspirator Teulon (unpubl.) found that more females were caught than males, suggesting that the females were less active. Females appeared to be less disturbed by the motion of the sampler moving around the tree and placing the collecting tube in their vicinity. This suggested that difference in mobility may have been a contributing factor in the resultant sex ratio of the yellow sticky board catches.

Table 5.3 clearly shows that more FALH adults were caught per tree by the sticky boards than by the D-Vac. This would be expected as the sticky boards were sampling continuously over the period of a week whereas the D-Vac sample was instantaneous. Nevertheless, the cost in terms of sampling effort would certainly favour the use of sticky boards. Fewer leafhoppers of other species were also trapped by the D-Vac on each tree (see Table 5.3).

Johnson and Taylor Suction Trap. Several attempts were made to establish a meaningful relationship between the number of male, female and total FALH's caught by the sticky board and those caught by the Johnson and Taylor suction trap. Using all the data available (i.e. 10 weeks) linear or non-linear regression often resulted in a

biologically meaningless line. It appeared that there were two relationships between these methods, one at each of different densities of the leafhopper population. At high densities the sticky boards sampled more FALH adults than the Johnson and Taylor suction trap but at lower densities the numbers were more even (see Table 5.4). Separating the data in such a way reduced the number of data points available and therefore the accuracy of any relationship determined would also be reduced. At low densities it was hard to discover any relationships between the two methods but for higher densities a straight line was established with a reasonable measure of correlation (see Figure 5.17). There was insufficient data available to determine if and at what density of the leafhopper population the relationship between the two methods changed. At best these results show there was a linear relationship between the number of FALH adults caught in the sticky boards and the number caught in the Johnson and Taylor suction trap at higher densities.

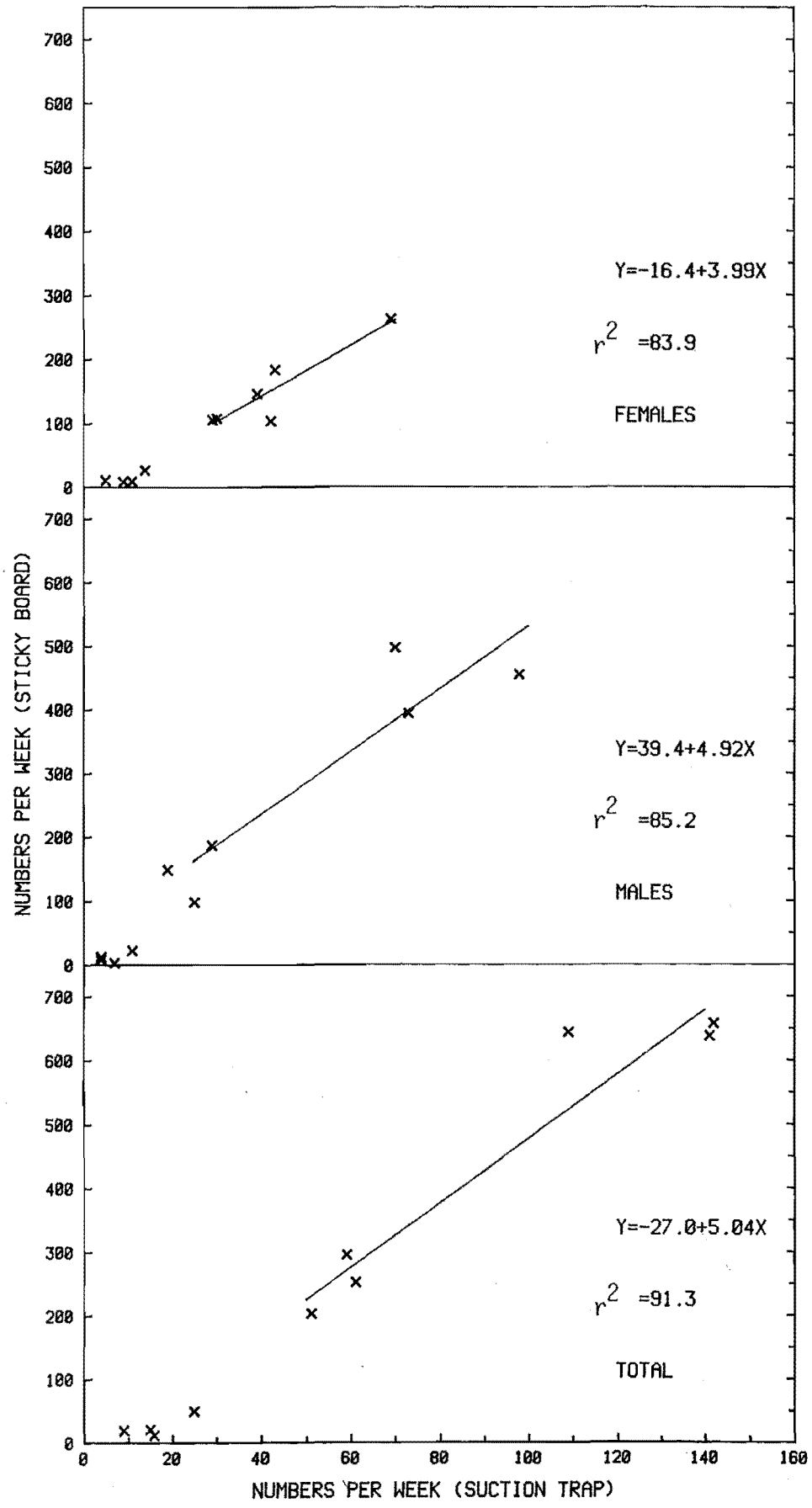
Although the ratio of male/female was always higher for the sticky boards than the Johnson and Taylor suction trap (except for the last sample) (see Table 5.4) the difference was not as large as experienced by the D-Vac. These results support the idea that males are preferentially sampled by the yellow sticky boards. The sample of leafhoppers collected by the yellow sticky board and the Johnson and Taylor suction trap would be similarly affected by any difference of mobility between the two sexes. Both methods sampled a population of flying insects over a continuous period of time. As the male/female ratio was still in favour of males this suggested that the difference in the ratio was attributable to a greater attraction by the males to the yellow boards. However, as the difference in the ratios was much smaller in this comparison than that with the D-Vac, it was possible that a greater mobility by the male was also important.

Sleeve Cages. FALH adults were first observed in the sleeve cages on 19 November 1981, this was only one week before they were first caught on sticky boards on the equivalent side of this orchard (Orchard 1). Adults of A. armatus were first trapped in the sleeve cages on 26 November 1981, one week after they had been observed on sticky boards on the same side of this orchard. Height did not appear to influence the initial trapping of either host or parasite adults. These results

Table 5.4: Male/female ratios of FALH adults for two sampling methods (sticky board and Johnson and Taylor suction trap) over time, showing sample size (n).

Weeks		1	2	3	4	5	6	7	8	9	10
STICKY BOARD		3.41	2.49	1.5	1.75	1.44	0.93	0.85	1.44	0.82	0.44
	n	644	638	657	294	252	203	50	22	20	13
JOHNSON-TAYLOR		1.79	2.28	1.06	0.97	0.45	0.86	0.79	0.36	0.8	0.77
	n	109	141	142	59	61	54	25	15	9	16

FIGURE 5.17 REGRESSION OF WEEKLY STICKY BOARD CATCHES AGAINST WEEKLY SUCTION TRAP CATCHES OF FALH ADULTS.



indicate that the sticky boards were accurate in determining the first flight of FALH and A. armatus.

C. Influence of Height on Sticky Board Catch.

The mean sticky board catches for the FALH adults (total, male and female) and all other leafhopper adults combined are shown in Table 5.5 for both sampling dates. Detailed results can be found in Appendix 7. The results of the analysis of variance are given in Table 5.6. In both samples the numbers of leafhoppers, other than FALH, decreased significantly with distance of the sticky boards from the ground although there were still a number of other leafhoppers trapped on the highest boards on both occasions. In relation to monitoring FALH populations it would be advantageous to place the sticky boards as high in the tree as possible to reduce the number of leafhoppers other than FALH caught but at a height easily accessible from the ground.

The FALH adult numbers increased significantly with distance from the ground on both sampling dates (see Table 5.6). This appeared to be the direct result of a disproportionate increase in males with height in relation to females. The significance of this was unclear. It was possible that males higher in the tree canopy became more attracted to the yellow sticky boards or became more mobile with height. Considering the size of the increases and the short distance between the sticky boards placed on the trees the increase in males with height was more likely a reflection of the real distribution of male FALH adults within the tree. Female numbers remained constant in the first sample and increased slightly in the second sample. This author could not find any biologically meaningful reason why the male numbers trapped increased with tree height while female numbers remained largely constant.

(iv) Summary.

The addition of Tack-trap coated clear acetate sheets to the yellow sticky boards only reduced the spectral reflectance of the boards a small amount. The benefit in sampling time and sample storage more than adequately compensated for this reduction. Weekly yellow sticky board samples trapped considerably more FALH adults than a D-Vac

Table 5.5: Mean FALH adult numbers (total, male and female) and all other leafhoppers combined, for sticky board catches at different heights for two samples in Orchard 1, 1981-82 season.

	Height (metres)			
	0.9	1.5	2.1	2.7
1st sample				
Total (FALH)	651.3	887.5	1703.3	-
Male (FALH)	208.3	498.2	1197.2	-
Female (FALH)	443.0	390.7	506.3	-
Other	42.8	20.7	11.8	-
2nd sample				
Total (FALH)	456.5	564.2	1167.7	1694.2
Male (FALH)	277.8	379.8	920.2	1414.2
Female (FALH)	178.7	184.3	247.5	280.0
Other	20.7	9.8	5.8	4.5

Table 5.6: F values from the analysis of variance of leafhoppper adult counts on sticky boards at different heights for two samples in Orchard 1, 1981-82 season.

Source	df	F value			
		total (FALH)	male (FALH)	female (FALH)	all other species
1st sample					
Height	2	25.7048 ***[a]	36.2015 ***	2.1041 ns	14.3700 ***
Tree	5	3.0078 ns	1.9767 ns	5.2800 *	1.3643 ns
2nd sample					
Height	3	42.2759 ***	60.7532 ***	4.7378 *	7.1192 **
Tree	5	1.2782 ns	1.0803 ns	2.5204 ns	0.9744 ns

[a] *** sig at $p < 0.005$, ** sig at $p < 0.01$, * sig at $p < 0.05$, ns-not significant

sample of the outer tree canopy. Sampling cost favoured the sticky boards. The sticky board also sampled more FALH adults than a Johnson and Taylor suction trap at high leafhopper population levels. At lower population levels the relationship was less well defined. Compared with these two alternative sampling methods the sticky boards appeared to preferentially sample males in relation to females, probably due to greater mobility and/or attractiveness to yellow by the male. Yellow sticky boards trapped emerging adults of both FALH and A. armatus at comparable times as those caught in nearby sleeve cages. Sleeve cages placed at different heights in the tree did not distinguish any difference with height in emergence of the above two species. The higher placement of sticky boards in apple trees significantly reduced the number of leafhoppers, other than FALH, trapped. Conversely, the number of FALH adults trapped increased with height due to a disproportionate increase of male numbers with height in relation to female numbers.

CHAPTER VI.

THERMAL SUMMATION AND ITS APPLICATION TO MANAGEMENT.

(i) Introduction.

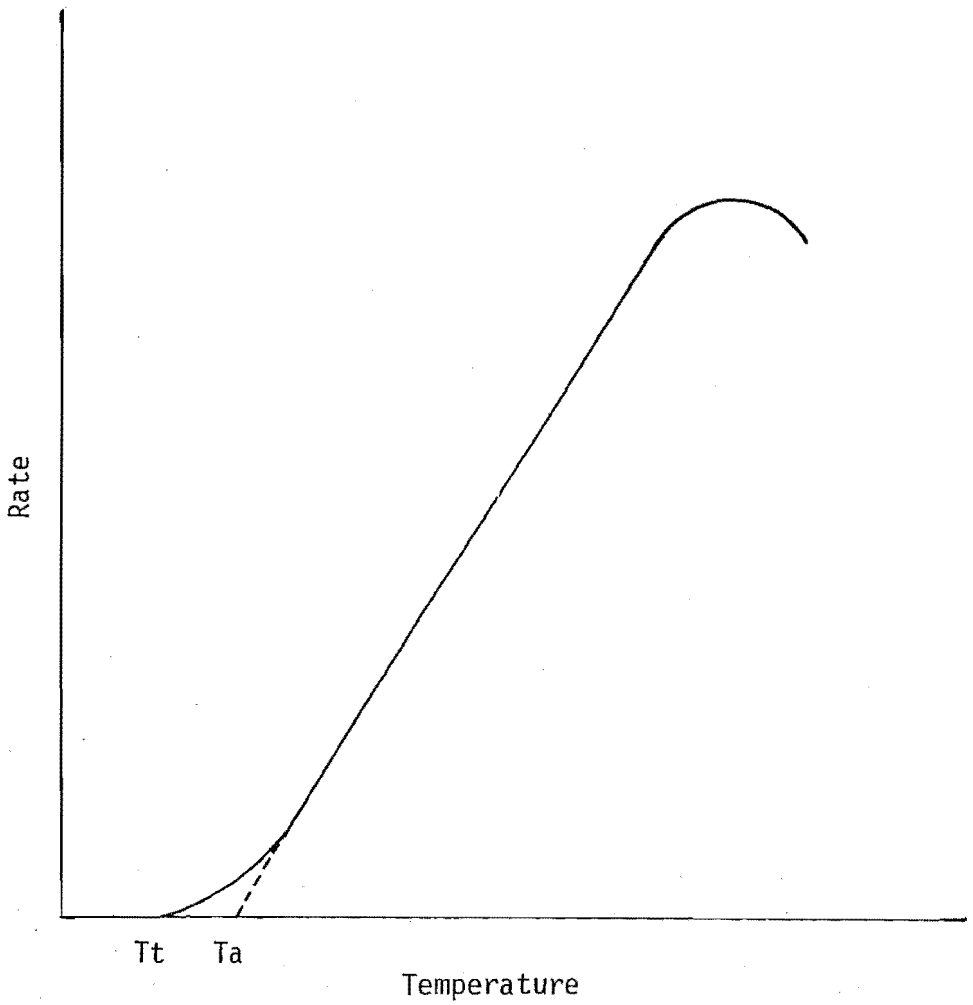
In any pest management programme an important component is the forecasting of pest activity (Trimble, 1983). Pest phenology rather than crop phenology has proved more reliable for timing control strategies (Welch et al., 1978) and degree-day (D°) summation has been widely used as a predictive model for estimating this. Allen (1976) outlined a number of insect examples where this approach has proved successful. Degree-day or thermal summation as a model, describes an organism's growth and development as a function of temperature. Due to its ease of application and the fact that within certain temperature limits it approximates observed values, it has been widely used in agronomy and other areas of applied zoology (Peairs, 1927).

The relationship between rate of development and temperature is usually S-shaped (Sanderson, 1910; Wigglesworth, 1972; Campbell et al., 1974; Sharpe and DeMichele, 1976) (see Figure 6.1). The thermal summation concept assumes that the rate of development is proportional to temperature in a linear relationship:

(1) $$K = b\ (T - Ta)$$

where K is the rate of development, b is a constant, T is the temperature and Ta is the base temperature. The 'base temperature', or that temperature which has been determined by the extrapolation of the straight line to the temperature axis (see Figure 6.1) has lead to some confusion in the literature. This temperature, has among other names, been called the 'developmental zero', the 'physiological zero', the 'critical point' and the 'threshold of development' (Peairs, 1927). These terms are inexact and do not distinguish the 'base temperature' from the true 'threshold of development' (Tt) which is the temperature at which development definitely ceases (see Figure 6.1). These points may occur at the same temperature but in a number of cases development has been recorded occurring at temperatures below the base temperature (Peairs, 1927). As the base temperature is easier to establish, it has

FIGURE 6.1: The relationship between the role of insect development and temperature showing the base temperature (Ta) and the true threshold of development (Tt). (Adapted from Campbell *et al.* (1974))



been used as an equivalent value to the true threshold of development and indeed Arnold (1959) suggested that the appropriate lower temperature for use in a linear heat unit system need not coincide with the physiological threshold of development. In practice field conditions have often been found to lie almost exclusively on the straight line section of Figure 6.1 (Campbell et al., 1974).

If Ta exists the time required for complete development (K) at temperature (T) is constant. The value K is termed the 'thermal constant'. Thus, where the linear relation between velocity and temperature holds, each developmental process will have a characteristic thermal constant and will require a fixed number of degree-days to bring it to completion (Wigglesworth, 1972). Thermal summation is the process of adding up the number of degree-days contributed at each temperature so that it is theoretically possible to predict the time necessary for the completion of development.

Some of the assumptions made in this simplified model of development have often proved incorrect. In the beet leafhopper, Eutettix tenellus (Baker) for example, there was evidence that not all stages of embryonic development were similarly affected by temperature (Harries, 1944). The base temperature is often far from the true threshold of development and development continues well below this point (Wigglesworth, 1972). At both ends of the straight line the development rate declines (Sharpe and DeMichele, 1976) and therefore, where environmental temperatures tend toward extremes under variable conditions, a linear relationship yields considerable error (Stinner et al., 1974). Other models have been proposed and used that describe the relationship between the development rate and temperature more exactly. Some of these: for example the logistic (Wigglesworth, 1972) and those derived from polynomial regression analysis (Tanigoshi et al., 1975) are purely empirical, whereas others, such as those put forward by Stinner et al. (1976) and Sharpe and DeMichele (1976) are more theoretical in concept.

The establishment of the base temperature has followed two basic approaches. First, the laboratory method where individual insects are reared in growth chambers at each of a number of constant temperatures (Morris and Fulton, 1970; Campbell et al., 1974). A major drawback of

this method is that in some cases an alternation of temperatures seems to stimulate development above that which is measured by constant temperature regimes (Hartzell, 1937). Alternating temperature regimes more closely approximate field conditions. In the second approach, the base temperature can be determined from data collected from the field if continuous temperature measurement is carried out at the same time. Arnold (1959) described three methods that fall into this category primarily concerned with plants but the principles of which apply equally to insects (Seyedoleslami, 1978). The methods based on field observations are however prone to errors made from inaccurate meteorological measurements. Standard meteorological measurements do not measure the climate of the insects' microhabitat (Baker, 1980).

In the Introduction it was pointed out that greater importance may have to be placed on the control of FALH in the future. The use of thermal summation should allow the time of chemical application to be more accurately predicted from the measurement of temperatures in the field. In the past, when more importance was placed on this insect's control, chemical applications were recommended by a number of authors just before the winged adults began to appear in both generations and/or after all the eggs had hatched (see Chapter 2.4). In both seasons of the population observed in Orchard 1, the first FALH adults trapped within the orchard (see Figure 5.1 and 5.2) occurred only one week after the first leaf sample without any 1st instars (see Figure 4.3 and 4.5). If control measures were taken just before the first flight of FALH adults in the first generation the development of A. armatus would also be least interrupted. The main adult emergence of this parasite in the first generation occurred after the first flight of FALH adults (see Chapter 5.1). In both seasons of sampling in Orchard 1, second generation adults were present some time before all 1st instars had disappeared from the leaf samples. The most appropriate time for insecticide application in the second season would be as close to the maturity of FALH nymphs as possible. At this time the numbers of free living adults of A. armatus would be decreasing in the orchard. If the FALH egg hatch is spread over some time a later spray may be needed to ensure adequate control of 1st instar nymphs but this would be at a time when parasite adult numbers in the orchard are high. The need for two insecticide applications in the second

generation would be dependent on the extent of leafhopper infestation within the orchard and the success of the control measures in the first generation. The timing of control strategies is therefore restricted in both generations if the conservation of the parasite species is attempted and the control measures are applied at the best possible time in relation to the target insect.

In this chapter experiments to establish the base temperature are reported through both laboratory observations and the 'least variability method' of Arnold (1959) using field data and the use of thermal summation in the management of FALH is investigated.

(ii) Materials and Methods.

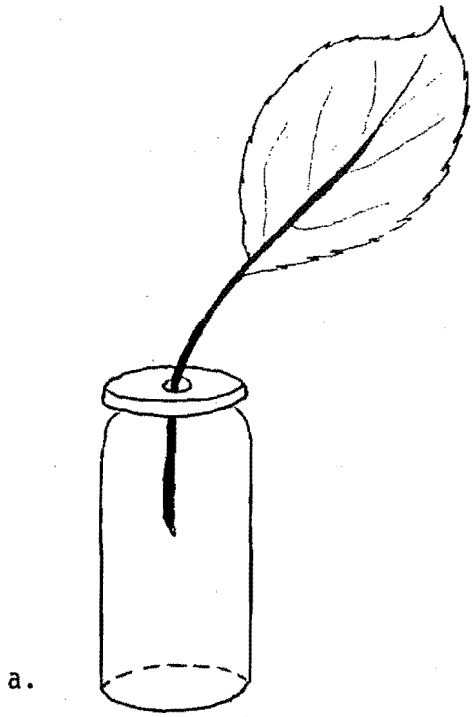
A. Laboratory Method.

First generation male and female FALH adults were caught by sweep net from Orchard 1 between 15 and 31 December 1981. From these, between 4 and 5 females were placed on single 'Sturmer' apple seedlings enclosed in perspex cages. The seedlings were then positioned within a 'walk-in' constant temperature room at 22°C for 24 hours to allow the oviposition of leafhopper eggs. The 'Sturmer' seedlings had previously been grown from seeds collected from Orchard 1 and had been kept free from leafhopper infestation. Each seedling was trimmed to approximately 7 leaves to allow easy observation of nymph hatching. After this time the adults were removed from the seedlings and replaced on other seedlings which were either positioned for further replication in the 22°C constant temperature room or left in the laboratory. The seedlings on which adults had been removed after oviposition were then placed in a watered tray under near constant temperature regimes of 9 ±2, 13 ±1, 15.5 ±1, 19 ±2, 22 ±1 and 25 ±2°C in 'walk-in' constant temperature-humidity rooms. The humidity was kept between 50 and 85% RH and photoperiod was 16L:8D. Light was supplied by two 65 watt fluorescent tubes. Approximately six apple seedlings, which had been exposed to mature females for 24 hours, were placed at each temperature.

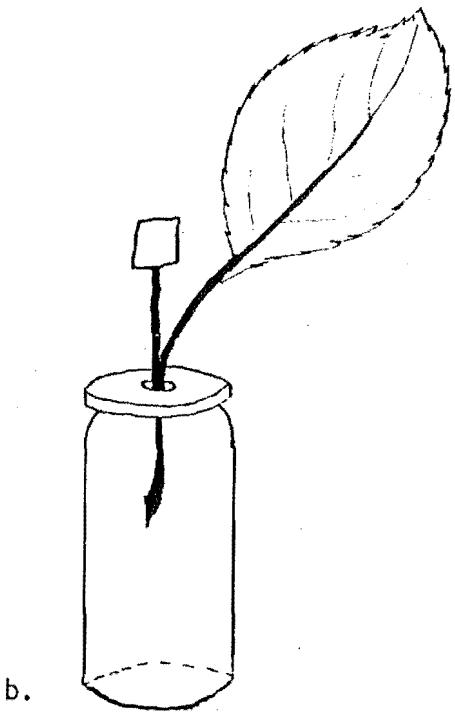
The seedlings in the temperature regimes of 9 and 13°C were observed every second day and those at 15.5, 19, 22 and 25°C were observed daily for the presence of hatched nymphs. When observed, the date at which the nymphs hatched was recorded and the nymphs were placed on a 'Sturmer' apple seedling that had been stripped of all but two leaves for ease of nymph observation. The development of the nymph was recorded through to maturity or death. As some nymphs died (especially at the lower temperatures) every attempt was made to replace them with nymphs reared on 'Sturmer' seedlings in the laboratory or from nymphs collected from the field which were of the same instar or younger. The two-leaved seedlings were replaced as necessary and when a nymph reached 5th instar the seedling was covered with a perspex cage to stop the adults escaping from the seedling. To determine the development time from adult to oviposition each nymph that developed to adult female was placed in a small perspex box (approximately 100 x 100 x 70 mm) with a single leaf whose petiole was placed through the plastic cap of a vial filled with water (see Figure 6.2a). The vial was embedded in polystyrene to keep it upright. A male specimen from either the other developmental studies or laboratory reared was also placed in this box. The leaf was changed daily and examined for the presence of eggs using the method outlined for the second season in Chapter 4.2. Other methods of determining the adult to oviposition development time were attempted including placing the leafhoppers in direct sunlight and using 5th instar nymphs collected directly from the field caged with twigged leaves in vials (see Figure 6.2b).

The time that each stage took to develop was established from the laboratory rearing not including the initial 24 hours at 22°C. Base temperatures for the development of egg to nymph, for each instar, and for egg to adult were established through linear regression on the reciprocal of development time (development rate) against temperature. Only those values that appeared part of the straight line were used in this regression. By setting the value of y in the straight line equation to zero and solving for x the base temperature was calculated. Thermal requirements of the developmental stages at each temperature were determined using equation (1) with the established base temperature, and a mean K was calculated.

FIGURE 6.2: Apple leaves placed in vials.



a.



b.

B. Field Data Method.

The 'least variability method' for determining the base temperature was described by Arnold (1959) and was used in this section. Dates at which 1st instar nymphs of the first generation were initially observed in the field on apple and the 1st instars of the following generation, were collected from a variety of sources (see Table 6.1). Maximum and minimum temperatures from nearby weather recording stations were also collected. For the data used from this thesis (see Chapter 4 and 5) meterological readings were made from a Stevenson's screen inside Orchard 1. Base temperatures of 6, 8, 9, 10, 10.5, 11, 12 and 14°C were used to determine degree-day accumulations based on the modified sine wave method of Allen (1976) for the time period between 1st instars of consecutive summer generations. The arbitrary value of 30°C was set as the upper threshold level. The accuracy of the upper threshold was not of great importance because the maximum temperature seldom went above 30°C in the data sets used. Degree-day summations of each base temperature were averaged for the four data sets and the coefficient of variation (C.V.) determined. The base temperature with the lowest coefficient of variation was assumed to be the proper base temperature for the development of 1st instar to 1st instar, that is, a complete life cycle.

Table 6.1: Summary of data used in thermal summation.

Source	Meterological Station	Start of Summation	End of Summation
this thesis (1)	on site	18/09/80	02/01/81
this thesis (2)	on site	01/10/81	12/01/82
Dumbleton (1934)	Nelson, N.Z.	25/09/32	01/01/33
Noble (1929)	Bathhurst Expt. Farm	18/09/28	30/11/28

(1) Orchard 1, 1980-81

(2) Orchard 1, 1981-82

The time between successive 1st instars also includes the time of adult to oviposition not determined in the laboratory studies. To have the best comparison with the base temperature and thermal summations established in the laboratory studies it would have been better to use

the time between 1st egg and 1st adult, but Noble's (1929) data could not have been used over this range as he/she did not record the initial presence of summer eggs. It was thought better to include the extra data set to reduce overall errors. Limited meteorological data sets may produce incorrect thresholds because of exceptional circumstances (Trimble, 1983). Furthermore the base temperatures established for all the development stages in the laboratory were very similar and it was likely that the base temperature for adult to oviposition would also be equivalent.

C. Forecasting Control Periods.

Thermal summations using the base temperature of 10.5°C and an upper threshold of 30°C were made between the following periods for both seasons on the populations of leafhoppers sampled in Orchard 1: first nymph recorded in the first generation to first adult of the first generation, first adult of the first generation to first adult of the second generation and first adult of the first generation to the first leaf sample of the second generation without 1st instar nymphs. The first adult of the second generation could not be accurately determined from the sampling data so the date of lowest FALH adult catch between generations was used (see Figure 5.1 and 5.2). Meterological data from a Stevenson's screen within Orchard 1 was used for these summations. Thermal summations were also made from an arbitrary date (1 May) to the initial adult flight in the first generation and the initial adult flight in the second generation for both seasons using data from the Christchurch Airport meterological station approximately 2.6 km south-west of the orchard. Using Christchurch Airport meterological data was necessary as no temperature recordings were made in Orchard 1 early in the season.

(iii) Results and Discussion.

A. Laboratory Method.

The mortality of FALH nymphs within these experiments was high. No individuals developed through from egg to adult at 9, 12 or 15.5°C and the mortality for hatched eggs to adult was 52.9, 37.5 and 16.7% for 19, 22 and 25°C respectively. The greatest single factor in the

death of the nymphs appeared to be their habit of wandering from the seedling and presumably dying through lack of food. Mortality was greatest in the first and fifth instar nymphs. Simonet and Pienkowski (1980) found a similar situation with the potato leafhopper, Empoasca fabae (Harris), and suggested this was probably due to the major changes that the fifth instar was undergoing prior to development to adult and handling with the first instar. It seems likely that the reasons for increased mortality among the first and fifth instars in this study were similar. The mortality of eggs within the apple leaves was difficult to determine but it was likely that the overall mortality would have been higher if this factor was included. Due to the high mortality a significant proportion of the results were made up of nymphs reared in the laboratory and placed in the appropriate temperature room. Table 6.2 summarises the mean number of days each development stage took to reach the next stage, the standard deviation and the number of observations. This table also shows the time to adult as the sum of the mean of each development stage. This was done to obtain egg to adult development times at the temperatures of 12 and 15.5°C. The development time (days) decreased with increasing temperature. The eggs especially, and the fifth instars, took a consistently larger proportion of the total development time than any other stage. In the three temperatures, 19, 22, 25°C there was no consistent difference of time to adult for the two sexes.

All attempts to establish the adult to oviposition time failed as no eggs were observed from any pairing of male and female. On only one occasion were a male and female pair observed copulating.

Development rate showed a linear relationship with temperature between 15.5 and 25°C for all development stages (except the first instar at 25°C) and for both measurements of egg to adult (see Figure 6.3). The base temperatures were determined as 10.7, 10.2, 9.7, 10.5, 11.0, 10.2 and 8.1°C for the egg, 1st instar, 2nd instar, 3rd instar, 4th instar, 5th instar and egg to adult respectively. All values of the coefficient of determination were above 0.95. These lines did not include the values at 9 and 12°C (and 25°C for the 1st instar) which did not appear to part of the linear function. The values at the lower temperatures were made up of a small number of replicates due to high mortality of all stages and it was likely that

Table 6.2: Development time (days) of FALH at constant temperatures.

Temperature (°C)	9	12	15.5	18	22	25
Stage						
Egg	-	62.9 (6.7/9)[a]	46.0 (1.0/3)	24.8 (1.4/17)	18.3 (1.4/16)	15.0 (0.4/12)
1st Instar	-	11.5 (0.7/2)	8.0 (-/1)	4.9 (0.5/11)	3.7 (0.5/12)	3.4 (0.7/10)
2nd Instar	-	9.4 (1.4/11)	8.3 (0.6/12)	4.0 (0.7/13)	3.5 (0.6/19)	2.8 (0.4/12)
3rd Instar	20.5 (2.1/2)	9.8 (0.9/10)	7.7 (0.5/9)	4.3 (0.5/23)	3.2 (0.6/18)	2.7 (0.5/15)
4th Instar	22.8 (3.1/8)	9.7 (0.9/9)	8.3 (0.5/7)	4.7 (0.8/21)	3.8 (0.5/18)	2.8 (0.6/16)
5th Instar	32.7 (5.5/3)	14.8 (1.7/6)	12.8 (0.8/6)	7.5 (0.8/19)	5.3 (0.6/19)	4.6 (0.6/16)
Egg-Adult[b]	-	-	-	49.1 (2.4/8)	38.1 (2.3/10)	31.5 (2.0/10)
Egg-Adult[b]		118.1	91.1	50.2	37.8	31.3

[a] mean (S.D/n)

[b] established from mean development of all life stages

FIGURE 6.3 DEVELOPMENT RATES FOR THE LIFE STAGES OF FALH UNDER VARIOUS CONSTANT TEMPERATURE REGIMES SHOWING THE ESTIMATED BASE TEMPERATURES.

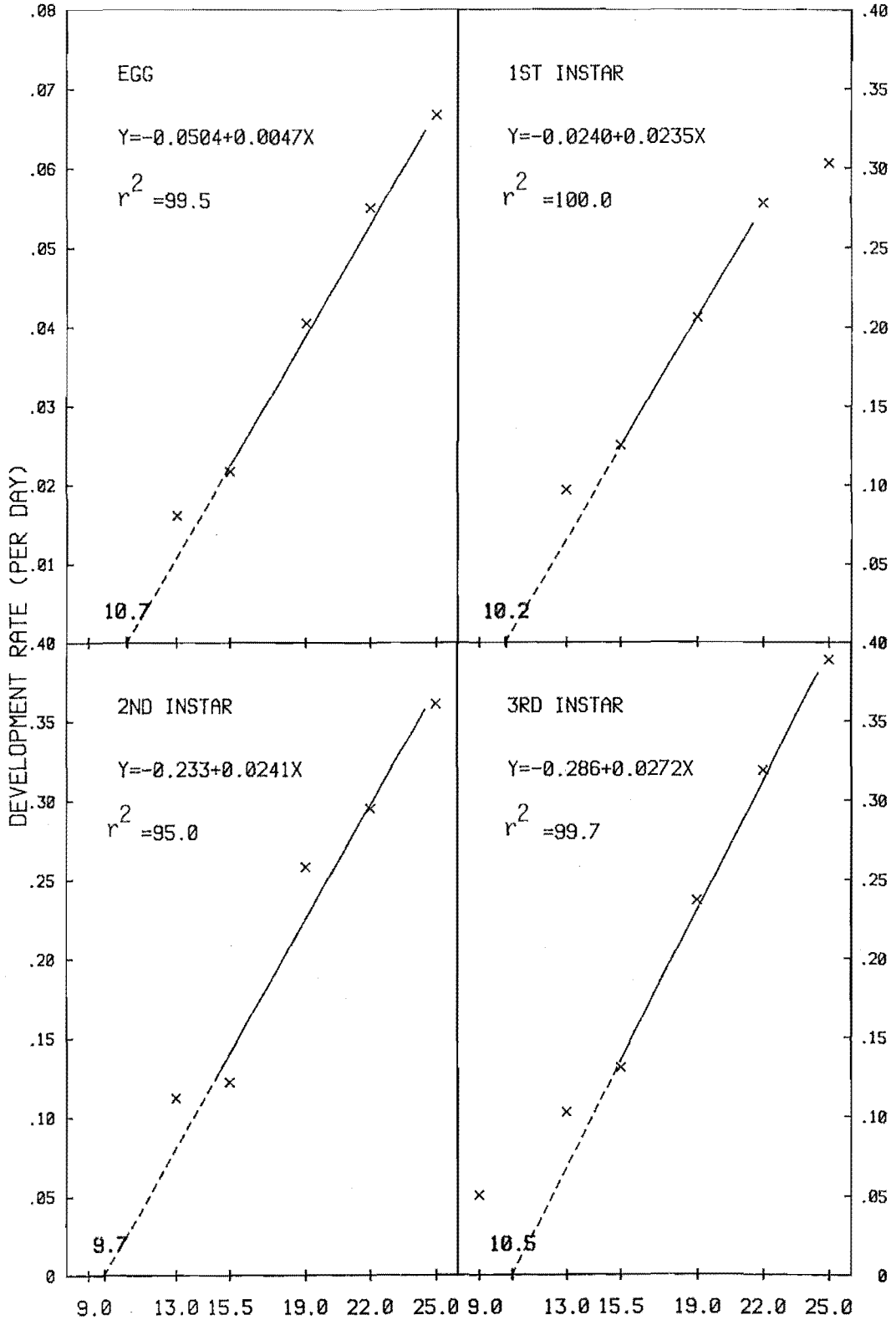
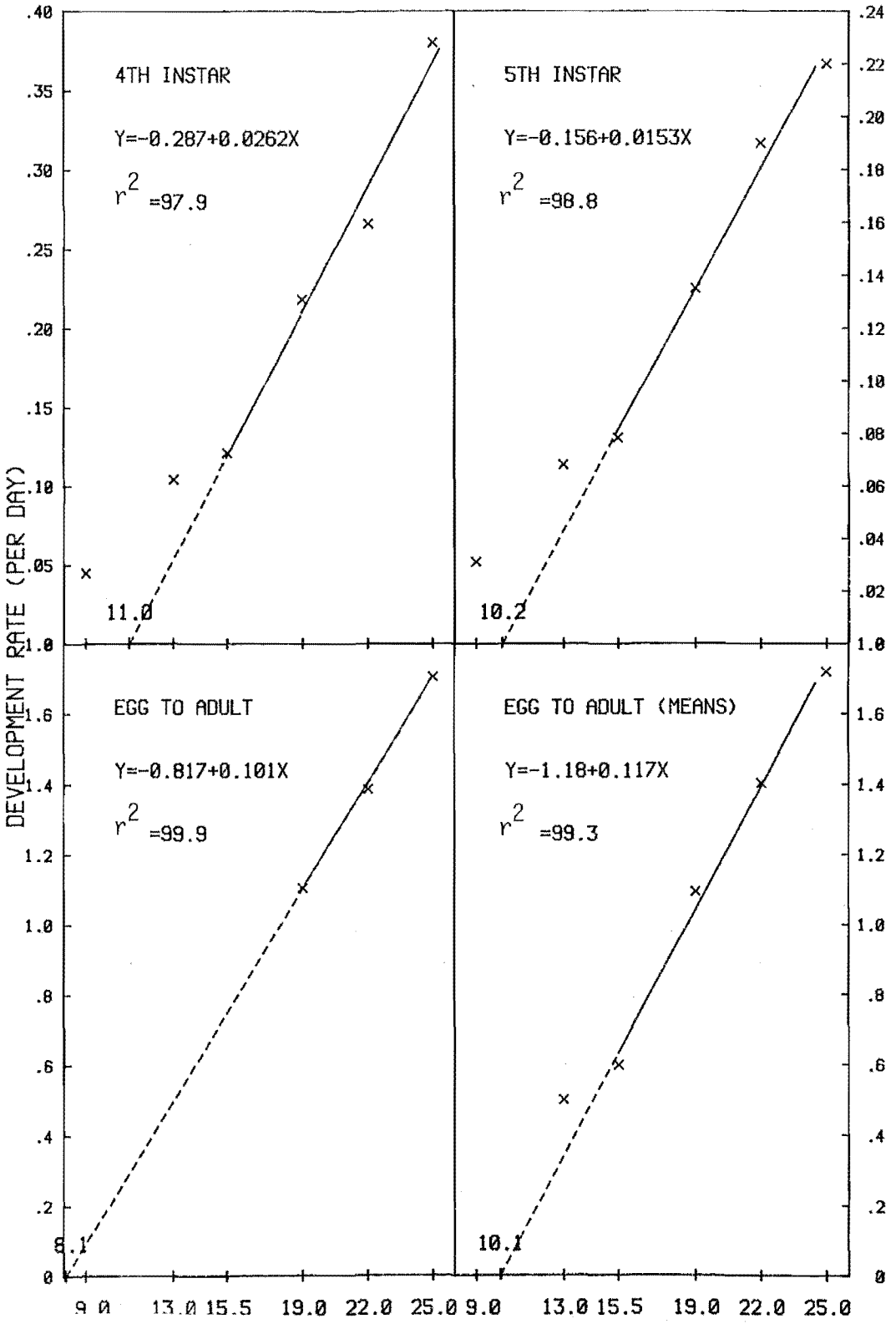


FIGURE 6.3 CONTINUED



there was selection for those individuals which could develop at low temperatures (Campbell et al., 1974). At such temperatures where mortality was high only a few of the fittest individuals were surviving. The base temperature values were consistent except for the egg to adult value of 8.1°C established from only three temperatures. Considerable extrapolation of these data is likely to compound any variation. The base temperature of 8.1 °C is unlikely to be as realistic as for other developmental comparisons. The base temperature for egg to adult (10.1°C) established from the addition of mean development time for each individual stage was likely to be a better indication of the base temperature as the straight line was based on more data points. This is confirmed by data in the next section.

The results gave little indication of the upper threshold. In the 1st instar it appeared that the line deviated at 25°C but in all the other stages and egg to adult this was not so.

The thermal constants for each developmental stage were determined at each temperature including the two egg to adult methods. The mean and standard error were determined for these which are shown in Table 6.3. The standard errors were generally small indicating the accuracy of the data. Although the mean number of degree-days for the egg to adult stage has a low standard error, it was much larger than the addition of each separate development stage, again indicating that the established base temperature of 8.1°C was probably inaccurate. Conversely the mean number of degree-days using the value of 10.1°C was closer to the sum of separate stages. Thus the thermal constant of FALH from egg to adult was estimated as 463.5 ±10.5 D°

B. Field Data Method.

The thermal summation of degree-days from the first 1st instar of one generation to the first 1st instar of the next summer generation is shown at each base temperature in Table 6.4 for the four data sets analysed. The coefficient of variation (C.V.) was lowest for 10.5 and 11.0°C over the range tested. The lower value was probably more correct as the time to adult in degree-days (458) was more consistent with that established for egg to adult in the laboratory. This value indicates the most appropriate base temperature for these data sets. Considering that all values of the base temperature estimated for each

Table 6.3: Development of life stages of FALH in physiological time (D°) under six constant temperatures.

Temperature (°C)	9	12	15.5	19	22	25	Mean ±S.E
Egg	-	?	220.8	205.8	206.8	214.5	212.0 ±3.53
1st instar	-	?	42.4	43.1	43.7	?	43.1 ±0.38
2nd instar	-	?	48.1	37.2	43.1	42.8	42.8 ±2.23
3rd instar	?	?	38.5	36.6	36.8	39.2	37.8 ±0.64
4th instar	?	?	37.4	37.6	41.8	39.2	39.0 ±1.02
5th instar	?	?	67.8	66.0	62.5	68.1	66.1 ±1.29
Egg-adult	-	-	-	535.2	529.6	532.4	532.4 ±1.62
Egg-adult[b]	-	?	491.9	445.9	449.8	466.4	463.5 ±10.46

- no development

? D° not calculated since development was not linear at these temperatures

[b] established from mean development of all life stages

Table 6.4: Thermal summation (D°) of field data using different base temperatures and showing the mean and coefficient of variation (C.V.)

Threshold Temperature (°C)	this thesis(1)	this thesis(2)	Dumble-ton(1934)	Noble (1929)	mean	C.V.
	thermal summation (degree-days)					
6	874.6	942.9	835.8	698.2	837.9	12.31
8	676.9	747.1	643.5	569.1	659.2	11.22
9	585.2	653.4	552.5	509.3	575.2	10.56
10	499.9	563.8	466.2	453.3	495.8	9.97
10.5	459.7	520.9	425.2	426.9	458.2	9.76
11	421.0	479.5	385.6	401.3	421.9	9.74
12	348.7	401.4	311.5	352.9	353.6	10.43
14	227.9	266.1	186.2	266.2	236.6	16.12

(1) Orchard 1,1980-81

(2) Orchard 1,1981-82

development stage in the previous section were between 9.7 and 11°C the base temperature determined here appears to be accurate. However, the temperature range over the dates of this summation were mostly within the straight line temperature range found in the previous section. When temperature values are extreme or range over a wide area the degree-day accumulation method results in erroneous answers (Stinner et al., 1974; Sharpe and DeMichele, 1977).

The use of thermal summation in this context, that is the control of FALH, would involve the summation of temperatures from the onset of egg development. This would involve thermal summation over a period when temperatures would initially be outside those of the straight line of the development rate/temperature relationship and therefore could give erroneous results. Unfortunately the limitations of this study did not allow the determination of the date and/or temperature when egg diapause was broken.

C. Forecasting Control Periods.

The results of thermal summations between selected dates is given in Table 6.5. Summing temperatures from an arbitrarily selected date (1 May) to first adult gave a marginally better agreement of the accumulated degree-days for both seasons than first nymph to adult. The accurate estimation of the appearance of first nymphs in the orchard can be difficult without daily observations and even then the observer may miss the small nymphs among the still tightly bound buds. Thermal summations between these dates were not accurate enough for the prediction of control measures in the field. The standard error of the mean for the arbitrarily selected date to first adult (25.2 D°) was equivalent to 12 and 5 calender days at the time of adult flight in the 1980-81 and 1981-82 seasons respectively. Determination of the first flight of FALH adults by some other method would therefore be needed. Nevertheless, the accumulation of degree-days could be used to approximate the time when this method could be initiated to accurately establish adult flight. A period of about 240 D° from 1 May would be suitable for this. It is noteworthy that the degree-days accumulated from 1 May to first adult (264 and 315) are much lower than the 463 D° determined in the laboratory for egg to adult. Therefore, a significant proportion of egg development must take place in the season

Table 6.5: Thermal summation of FALH between selected dates.

	Season 1.		Season 2.		
	Date	D°	Date	D°	Mean ±S.E.
First nymphs observed.	18/09/80	197.0[1]	1/10/81	160.5[1]	178.8 ±18.3
First adult (1st generation)	12/11/80		17/11/81		
Arbitrary date.	1/05/80	315.2[2]	1/05/81	264.8[2]	290.0 ±25.2
First adult (1st generation)	12/11/80		17/11/81		
Arbitrary date.	1/05/80	774.7[2]	1/05/81	773.0[2]	773.0 ±0.1
First adult (2nd generation)	28/01/81		1/02/82		
First adult (1st generation)	12/11/80	492.4[1]	17/11/81	529.8[1]	511.1 ±18.7
First adult (2nd generation)	28/01/81		1/02/82		
First adult (1st generation)	12/11/80	737.9[1]	17/11/81	742.7[1]	740.3 ±2.4
Absence of 1st instars	4/03/80		9/03/81		

[1] Stevenson's screen inside Orchard 1.

[2] Ch-Ch Airport met data

in which they were oviposited before they go into diapause.

The thermal summations from 1 May to the second adult flight were in close agreement for both seasons. The difference between the two flights of each season was also in moderate agreement. Although agreement in the thermal summations for the second flight were excellent, those for the first flight were poor. It was likely that diapause had an important influence on these results and until the diapause requirements of this insect are investigated it is unlikely that any thermal summation for the first generation will prove accurate. The range of temperature values outside the straight line development relationship may have also been responsible for some of this error. Nevertheless, there was a moderate agreement of the thermal summation between flights. The standard error of the mean between flights was equivalent to less than four calendar days at the time of the second adult flight in both seasons. Considering that samples were taken approximately every seven days in both seasons this error is not surprising. These summations could either be used to determine spray times (511 D° after the first adult of the first generation) or to approximate the time when other methods could be used to give a more accurate time to spray. If there were no adults of the first flight there would probably be no need to spray. The thermal summations between first adult of the first generation and absence of 1st instars nymphs in the second generation were of good agreement. Therefore, if needed, a third chemical application could be made some time after 740 D° had elapsed from the time of first flight in the first generation. The integration of these results with those from other chapters will be discussed further in Chapter 7.

(iv) Summary.

The appropriate base temperatures for use in thermal summation were found to be between 9.7 and 11.0°C by laboratory studies and the 'least variability method' of Arnold (1959). The so called 'upper threshold of development' was not established. A thermal constant of 463.5 ±10.5 D° from egg to adult was established from laboratory studies. The use of thermal summation was found to be inaccurate in predicting key times for chemical application in the first generation.

In the second generation, the accuracy of prediction was improved and a chemical application could be applied at 511' D after the first adult of the first generation. Thermal summation may be used to indicate when it is appropriate to initiate other monitoring methods. A second insecticidal application in the second generation may be needed after 740 D° have elapsed from the first flight of first generation leafhoppers.

CHAPTER VII.

SUMMARY AND RECOMMENDATIONS.

The stated aims of this thesis were to gather basic biological information that may help in the integrated management of FALH. In this chapter the biological information established in this thesis is given in a summary of results. The use of this information and that gathered from the literature is then discussed specifically in relation to sampling and the management of this insect. Finally, areas where further research is important is discussed.

7.1 Summary of Results.

Sampling of leafhopper populations occurred in three orchards: an orchard abandoned for over five years, an uninfested research orchard that had insecticide applications discontinued over the study period, and a commercial orchard with regular insecticide applications.

In two of the apple orchards sampled by yellow sticky boards over two seasons at least six species of leafhoppers were trapped: T. froggatti, R. tenerrima, Z. zealandica, Z. dumbletoni, E. melissae and T. lethierryi. The latter two species were found in very small numbers and only FALH appeared to be living directly on apple. The presence of suitable host plants was thought to be the reason for the numbers of other leafhoppers trapped. Detailed sampling was therefore restricted to FALH. It should be emphasised that much of the sampling was carried out in the two outside rows of the abandoned orchard and the results obtained may not be completely applicable to FALH influenced by insecticide applications.

(i) Biology.

Phenology. At least two generations of FALH were present in the abandoned orchard in the two seasons sampled. This was apparent in the leaf samples of summer eggs and nymphs and by yellow sticky board samples of adults. It was possible that a partial third generation

existed but this was not established. The development of this insect over time varied with season and to a smaller extent with position in the orchard.

Distribution within the tree. The results described here are from the abandoned orchard. A small sample of overwintering eggs on tree branches suggested there was no preference for egg oviposition in relation to five years of branch age, cardinal direction (quadrat) and height (above and below 2 m). Likewise two seasons of leaf samples for summer eggs showed no preference of oviposition for height (above and below 2 m) in both seasons and cardinal direction (quadrat) and position in the canopy (inside and outside) for separate seasons. There was no consistent preference for nymph position in relation to tree height (above and below 2 m) over two seasons of leaf samples although in some of the samples there were significantly more nymphs at different heights. Nymphs were found in equivalent numbers in different cardinal directions (quadrats) and in different positions of the canopy (inside and outside) in separate seasons. Nymphs may have preferred older as opposed to younger leaves. On two dates in the 1981-82 season, sticky board samples showed an increasing number of FALH adults caught with height. This was due to a disproportionate increase of males with height in relation to females. Emergence of first generation adults of both FALH and A. armatus did not appear to be affected by height in the tree.

Dispersion. The description of the pattern of distribution was established from indices of Taylor's power law and Iwao's patchiness regression from sampling in the abandoned orchard. Overwintering eggs on five years of branch growth were described as randomly dispersed, cohesive groups of individual eggs. In two seasons of summer egg leaf samples, the distribution was clumped with the basic component of the distribution a single egg. The nymphal instar distributions were both contagious and random with the basic component of the distribution being individuals. In the second season the distribution of nymphs was generally more random than in the first. Of the 27 distributions analysed, Taylor's power law fitted the data better than Iwao's patchiness regression on 26 occasions. Only four distributions were described differently by the two methods. No attempt was made to describe the dispersion of FALH adults.

Migration. The movement of FALH adults was studied from infested trees into a nearby uncontrolled orchard of previously low infestation. Although the uninfested orchard was always available for colonisation, migration only occurred in observable numbers when conditions on the infested trees became unsuitable. It appeared that migration over short distances was mainly influenced by the condition of food plants and to a lesser extent by the prevailing wind.

Population increase. FALH adult numbers quickly increased when insecticidal control measures were removed.

Host plants. FALH adults were trapped in significant numbers on yellow sticky boards placed outside the abandoned orchard amongst blackberry bushes and to a lesser extent in blackberry outside a commercial orchard. The time of trapping and the numbers trapped strongly suggested that a separate population of FALH existed in the blackberry.

Parasitism. A conservative estimate of parasitism by A. armatus on FALH winter eggs was between 30-53% in trees in the abandoned orchard. At peak FALH summer egg counts in the abandoned orchard, a conservative estimate of parasitism by A. armatus was 20%. This increased to nearly 100% as the season progressed. A. armatus adults were trapped on yellow sticky boards within the abandoned orchard and appeared to go through two generations, being well synchronised with the FALH population. The numbers of this parasite trapped where FALH numbers were low suggested that they parasitised other leafhoppers as well. No observations were made of the dryinid parasite Aphelopus typhlocybae Muesbeck in the three orchards that were sampled.

Predation. There was evidence that spider predation was common in the abandoned orchard.

Thermal summation. The appropriate base temperatures for different stages of development of FALH were found to be between 9.7 and 11.0°C by laboratory studies and measurement of field data. The upper threshold of development was not determined. A thermal constant of 463.5 ±10.5 D° for egg to adult was established from laboratory studies. Thermal summation was not accurate at predicting events in the first generation but gave reasonable predictions in the second

generation.

Control. Numbers of adults of both FALH and A. armatus were considerably lower in the regularly sprayed commercial orchard than in the abandoned orchard.

(ii) Sticky Board Sampling.

The use of acetate sheets on yellow sticky boards did not significantly reduce the percentage reflectance of the yellow board particularly when considering the benefit gained from their use in sampling. The sticky board appeared to sample a larger proportion of a FALH population for an equivalent cost compared with a D-Vac suction machine (at all densties) and a Johnson and Taylor suction trap (at high densities). Sticky traps appeared to preferentially sample FALH males as opposed to females. Higher placement of sticky boards in the canopy of apple trees trapped a higher proportion of FALH compared to the other non-arboreal leafhoppers. Yellow sticky board samples trapped emerging adults of FALH and A. armatus at similar times to sleeve cages placed on tree branches.

7.2 Recommendations.

(i) Sampling plan.

The full development of a sampling plan for FALH was not investigated in this thesis. Nevertheless, a few pertinent comments can be made in reference to the results of this thesis for use in assessing infestation and taking control measures. To gain a quantitative estimate of the FALH population leaf sampling of nymphal stages would be most appropriate. This utilises a sampling unit that fulfils many of the requirements of Morris (1955) and would seem to be less time consuming (for a similar error) than sampling either summer or winter eggs. Furthermore, sampling leaves did not involve the technical equipment or elaborate methods needed for egg sampling; this would be especially true if the instars were not differentiated. Nymphal leaf counts that do not require instar differentiation can be

carried out by experienced personnel without removing leaves from the trees.

Leaf samples assess only those nymphal leafhoppers which are directly attacking the apple trees, but in comparison sticky boards sample all adult leafhoppers found within the tree canopy including those which do not damage the crop. Leaf counts also have a lower sampling error and nymphs appear to have no preference for height (above and below 2 m), position (inside and outside) and cardinal direction (quadrat) in the the tree canopy. The sticky board catches were the combined result of FALH adults attracted to them and those adults that were caught by chance. Little is known about the influences of colour on attraction of leafhoppers. Furthermore, different environmental conditions influence the result of FALH flight and therefore the sticky board sample. Leaf samples sample those nymphs on the tree irrespective of the environmental conditions. Sticky boards would be ideal for qualitative sampling. For a low cost, sticky boards sample a large number of individuals and are efficient at sampling low densities. Therefore sticky boards could be used for a presence or absence measurement and leaf samples to determine the numbers present.

(ii) Management.

At present FALH populations are adequately controlled by the application of insecticides for 'key pests' within the apple orchard. Nevertheless, resistance to the presently used organophosphate insecticide (azinphosmethyl) is clearly possible since closely related species show resistance overseas (see Chapter 2.4). Attempts to reduce the potential for buildup of resistance of this insect are therefore desirable, considering the importance of azinphosmethyl to 'integrated mite control' in New Zealand (see Penman et al., 1979).

In the literature there are three approaches to the management of resistance (Georghiou, 1981) and of these only 'management by moderation' is relevant to work in this thesis. Management by moderation recognises that susceptible genes must be conserved. The most appropriate way to do this with FALH would be to make available alternate host plants on which susceptible populations that are not

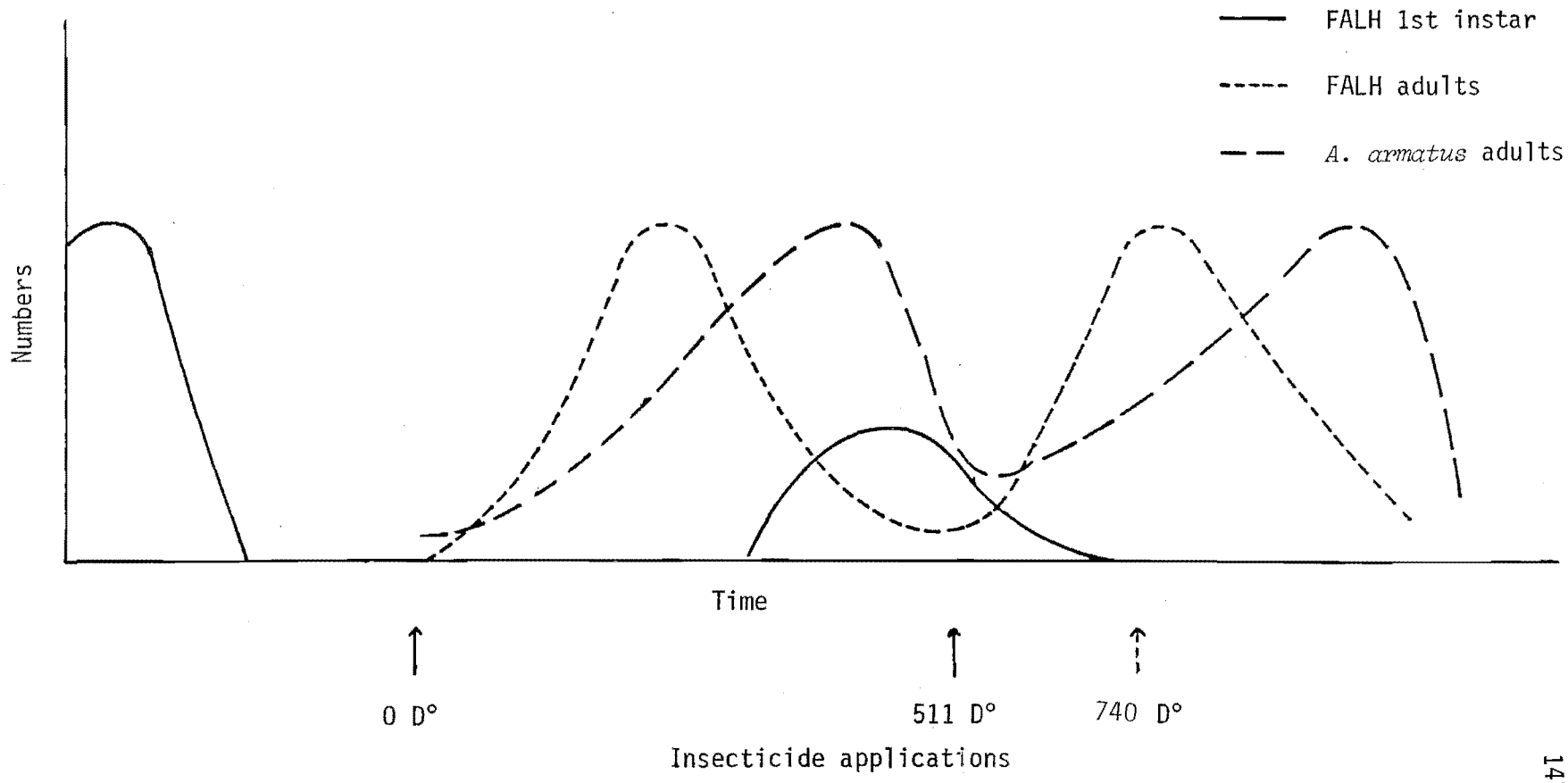
subject to insecticide application can survive. Dilution of FALH under constant chemical selection by susceptible leafhoppers not under this pressure would delay the onset of resistance. In the orchards sampled in this thesis blackberry was found to be such a host plant. FALH populations existed on blackberry in appreciable numbers although not to the same extent as those found on unsprayed apple trees. The use of unsprayed apple trees (or even hawthorn) in this way, may also prove valuable. Conversely, they may introduce numbers of FALH beyond an appropriate level of infestation. Unsprayed hosts may also impose alternative problems for orchard management as 'key pests', which may have broad host requirements and a low threshold of infestation (such as leafrollers) could also be encouraged inside the orchard.

The presence of suitable host plants such as blackberry would also increase the number of other leafhopper species and therefore encourage parasitism by A. armatus in the orchard.

It is probable that in some generations or even seasons specific control for FALH will not be needed and this will help delay resistance by reducing the selection pressure. A suitable economic threshold level of infestation would have to be established to determine the need for control. A leaf sample of nymphs just before spray application would appear to be the most appropriate method and time for this.

With the increasing introduction of IPM strategies, applications of insecticides may be reduced in the apple orchards (Thomas, pers. comm.) reducing the selection pressure on all susceptible insects including FALH. This is beneficial for continued FALH control only if insecticide applications continue to be applied at important times in the leafhopper's life cycle. Both the literature and results of this thesis suggest the most appropriate time for insecticide application would be as follows (see Figure 7.1). Insecticide applications just before the first adults of the first generation appear in the orchard would ensure that all nymphs have hatched from egg and are present on the foliage. At this time very few adults of A. armatus have emerged from the protection of the FALH egg embedded in the bark and therefore parasites of the first generation would largely be conserved. One insecticide application at this time should be all that is necessary for the first generation as all nymphs would be exposed.

FIGURE 7.1: Insecticide application times for FALH.



An insecticide application at the same time in the second generation (or when leafhopper adults present between the two generations are at their lowest) would ensure that the parasite population was also least affected. This is approximately 511 D° after the first flight of the first generation FALH adults. At this time there is a definite decrease in parasite numbers in the orchard although there are still a number of first instar nymphs present after this time (see Figure 7.1). If needed, a third insecticide application could be applied 740 D° after the first adult observed in the first generation. If applied at this time a large proportion of the parasite population will also be destroyed. It is probable that the numbers of nymphs missed by the first application of the second generation would be small and below any threshold level of infestation (if established). Furthermore, the number missed by this application may help reduce selection for resistance.

Therefore, if FALH populations become more important in relation to control from either resistance or through the reduction in insecticides the following strategy based on an integrated approach for this insect alone is recommended.

A leaf sample of FALH nymphs should be taken immediately the first FALH adult is caught in a yellow sticky board trap placed in a part of the orchard optimal for insect development. If the nymph sample is larger than a yet undetermined threshold of infestation, immediate insecticide applications should be made. If the infestation level is below the threshold no action need be taken. Approximately 511 D° after the first adult catch of the first generation a second leaf sample for nymphs should be taken. Insecticide applications should be carried out as previously. If the infestation of nymphs exceeds the threshold after the second spray a third insecticide application may be made 740 D° after the first adult of the first generation caught in the sticky traps.

(iii) Future Research.

This thesis has gathered some basic biological information on which the control of FALH can be based. Nevertheless, there are still areas that need further investigation if an integrated management approach to control is to be totally successful.

A more detailed investigation of parasitism by A. armatus and spider predation would lead to the maximisation of biological controls for FALH. Alternatively, chemical control will need to be investigated further, especially if resistance to azinphosmethyl becomes apparent. This would involve establishing the most effective substitute insecticide that adequately controlled FALH with least disruption to other forms of control in the apple orchard ecosystem.

The understanding of FALH's diapause requirements should lead to a more accurate use of thermal summation in the first generation.

Threshold levels of infestation are an important component of any pest manangement programme. If the present importance of this insect increases a threshold would need to be established so that insecticides could be applied sparingly.

A detailed analysis of the costs of the various methods of sampling FALH would be valuable to establish beyond doubt the most appropriate methods for determinig infestation levels and important times within the population of FALH.

Finally, the control of this insect should be integrated with the total pest complex within the apple orchard. This is of primary importance.

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Appendix 1: Common ground cover plants of Orchards 1 and 2.

Orchard 1.

Polygonaceae

Rumex obtusifolius. (Broad leaved dock)

Caryophyllaceae

Stellaria media. (Chickweed)

Rubiaceae

Galium aparine. (Cleavers)

Ranunculaceae

Ranunculus repens. (Creeping buttercup)

Brassicaceae

Capsella bursa-pastoris. (Shepherd's purse)

Sisymbrium officinale. (Hedge mustard)

Fabaceae

Trifolium repens. (White clover)

Apiaceae

Conium maculatum. (Hemlock)

Lamiaceae

Lamium amplexicaule. (Henbit)

Scrophulariaceae

Veronica persica. (Scrambling speedwell)

Asteraceae

Cirsium arvense. (Californian thistle)

Cirsium vulgare. (Scotch thistle)

Taraxacum officinale. (Dandelion)

Poaceae

Bromus diandrus. (Ripgut brome)

Dactylis glomerata. (Cocksfoot)

Holcus lanatus. (Yorkshire fog)

Hordeum murinum. (Barely grass)

Lolium perenne. (Perenial ryegrass)

Poa pratense.

Appendix 1 continued:

Orchard 2.

Fabaceae

Trifolium repens. (White clover)

Plantaginaceae

Plantago lanceolata. (Narrow leaved plaintain)

Asteraceae

Taraxacum officinale. (Dandelion)

Poaceae

Bromus catharticus. (Prairie grass)

Dactylis glomerata. (Cocksfoot)

Lolium multiflorum. (Italian ryegrass)

Appendix 2: Untransformed overwintering egg and parasite counts (per 50 sq mm) for treatment means, schedules 1, 2 and 3.

Schedule 1.

Egg counts. Overall mean: 10.2

A	1	2	3	4	5	$\bar{x}$
Q						
N	10.2	20.4	8.0	7.2	19.3	13.0
W	7.4	4.9	22.0	7.4	11.7	10.7
S	10.5	14.4	2.4	7.5	7.9	8.5
E	7.4	7.1	5.7	12.5	10.6	8.6
$\bar{x}$	8.8	11.7	9.5	8.6	12.4	

Parasite counts. Overall mean: 4.57

A	1	2	3	4	5	$\bar{x}$
Q						
N	6.97	14.69	3.21	1.90	4.10	6.17
W	2.74	2.00	12.75	2.42	2.27	4.44
S	5.77	7.13	0.84	1.78	2.09	3.520
E	4.69	6.08	3.86	4.29	1.85	4.16
$\bar{x}$	5.04	7.48	5.17	2.6	2.58	

Schedule 2.

Egg counts. Overall mean: 10.9

Q	N	W	S	E	$\bar{x}$
H					
1	13.1	8.1	11.0	7.9	10.0
2	8.7	11.6	19.1	7.9	11.8
$\bar{x}$	10.9	9.8	15.1	7.9	

Parasite Counts. Overall mean: 3.48

Q	N	W	S	E	$\bar{x}$
H					
1	4.70	2.54	3.01	0.0	2.56
2	2.56	3.30	10.81	0.93	4.4
$\bar{x}$	3.63	2.92	6.91	0.46	

Appendix 2 continued:

Schedule 3.

Egg counts. Overall mean: 13.7

Q	N	W	S	E	$\bar{x}$
H					
1	12.4	8.9	3.5	16.7	10.4
2	10.4	13.4	13.8	30.4	17.0
$\bar{x}$	11.4	11.1	8.6	23.5	

Parasite counts. Overall mean: 7.3

Q	N	W	S	E	$\bar{x}$
H					
1	5.2	5.0	1.8	11.9	6.0
2	4.2	10.5	5.9	14.1	8.7
$\bar{x}$	4.7	7.8	3.8	13.0	

Appendix 3: Constituents of the lactophenol clearing solution, per 1000ml.

200ml	liquified phenol
200ml	water
200ml	lactic acid
400ml	glycerine (98.12 per cent)

Appendix 4: Untransformed summer egg treatment means per leaf, Orchard 1, 1980-81 and 1981-82.

Season 1981-82.

17.12.80 (North) Overall mean: 1.14

Q	N	W	S	E	$\bar{x}$
H					
U	0.80	0.95	1.30	1.40	1.11
L	1.05	0.70	1.50	1.40	1.16
$\bar{x}$	0.93	0.83	1.40	1.40	

7.1.81 (North) Overall mean: 2.28

Q	N	W	S	E	$\bar{x}$
H					
U	1.85	1.75	2.45	1.65	1.93
L	2.20	2.10	1.65	4.55	2.63
$\bar{x}$	2.03	1.93	2.05	3.10	

7.1.81 (south) Overall meam: 2.11

Q	N	W	S	E	$\bar{x}$
H					
U	2.70	2.70	2.55	2.45	2.6
L	1.75	1.40	1.70	1.65	1.62
$\bar{x}$	2.22	2.05	2.13	2.05	

28.1.81 (North) Overall mean: 1.63

Q	N	W	S	E	$\bar{x}$
H					
U	1.75	1.30	0.70	2.15	1.48
L	1.65	1.60	2.40	1.45	1.78
$\bar{x}$	1.70	1.45	1.55	1.80	

Season 1981-82.

23.12.81

P	1	2	$\bar{x}$
H			
U	2.70	3.30	3.00
L	2.62	2.15	2.39
$\bar{x}$	2.66	2.72	2.69

Appendix 4 continued:

30.12.81

P	1	2	$\bar{x}$
H			
U	2.53	3.10	2.81
L	3.30	3.13	3.21
$\bar{x}$	2.81	3.11	3.01

12.01.82

P	1	2	$\bar{x}$
H			
U	1.80	2.00	1.90
L	1.67	3.05	2.36
$\bar{x}$	1.74	2.53	2.13

1.02.82

P	1	2	$\bar{x}$
H			
U	0.93	0.90	0.91
L	1.05	0.85	0.95
$\bar{x}$	0.99	0.88	0.93

Appendix 5: Treatment means for untransformed combined nymph counts (per 5 leaves) for schedules 1 and 2, Orchard 1, 1980-81 and 1981-82.

Season 1980-81.

Schedule 1.

28.9.80

Q	N	W	S	E	$\bar{x}$
H					
U	6.25	7.5	6.25	5.63	6.41
L	2.75	5.0	3.63	4.38	3.94
$\bar{x}$	4.5	6.25	4.94	5.0	5.17

12.10.80

Q	N	W	S	E	$\bar{x}$
H					
U	4.50	3.38	6.63	3.63	4.53
L	3.63	5.13	4.75	4.63	4.53
$\bar{x}$	4.06	4.25	5.69	4.13	4.53

25.10.80

Q	N	W	S	E	$\bar{x}$
H					
U	5.63	3.13	3.0	4.5	4.06
L	3.88	3.63	5.75	3.50	4.19
$\bar{x}$	4.75	3.38	4.38	4.00	4.13

10.11.80

Q	N	W	S	E	$\bar{x}$
H					
U	0.88	2.25	1.00	1.88	1.5
L	2.75	3.25	2.88	2.88	2.94
$\bar{x}$	1.81	2.75	1.94	2.38	2.22

7.1.81

Q	N	W	S	E	$\bar{x}$
H					
U	0.5	1.25	1.13	0.75	0.91
L	0.25	1.0	0.25	0.75	0.56
$\bar{x}$	0.38	1.13	0.69	0.75	0.73

Appendix 5 continued:

1.2.82

P	I	O	$\bar{x}$
H U L	3.83	3.67	3.75
$\bar{x}$	4.67	4.08	4.38

8.2.82

	Y	A	L	$\bar{x}$
	1.56	1.83	1.82	1.7

15.2.82

P	I	O	$\bar{x}$
H U	2.33	3.33	2.83
L	1.58	2.33	1.96
$\bar{x}$	1.96	2.83	2.40

Schedule 2.

7.10.81

P	U	I	O	$\bar{x}$
	3.58	1.42	2.33	2.44

20.1.81

P	U	I	O	$\bar{x}$
	1.92	1.00	2.25	1.72

1.2.82

P	U	I	O	$\bar{x}$
	3.58	1.42	2.33	2.44

8.2.82

	Y	A	$\bar{x}$
H U	0.83	1.83	1.33
L	1.10	1.22	1.16
$\bar{x}$	0.97	1.53	1.25

15.2.82

P	U	I	O	$\bar{x}$
	1.25	0.58	1.42	1.08

Appendix 6: Contingency tables for comparison of the D-Vac suction collector and sticky board.

TREE N1.

	STICKY	D-VAC	TOTALS
MALE	26 (22.6)	3 (6.4)	29
FEMALE	48 (51.4)	18 (14.6)	66
TOTALS	74	21	95

TOTAL CHI SQUARE=

0.51 + 1.81
+ 0.23 + 0.80 = 3.35 SIG at $p < 0.1$

TREE S1.

	STICKY	D-VAC	TOTALS
MALE	29 (28.0)	2 (3.0)	31
FEMALE	47 (48.0)	6 (5.0)	53
TOTALS	76	8	84

TOTAL CHI SQUARE=

0.03 + 0.31
+ 0.02 + 0.18 = 0.54

TREE N2.

	STICKY	D-VAC	TOTALS
MALE	45 (42.1)	9 (11.9)	54
FEMALE	72 (74.9)	24 (21.1)	96
TOTALS	117	33	150

TOTAL CHI SQUARE=

0.20 + 0.70
+ 0.11 + 0.39 = 1.40

TREE S2.

	STICKY	D-VAC	TOTALS
MALE	40 (34.7)	0 (5.3)	40
FEMALE	39 (44.3)	12 (6.7)	51
TOTALS	79	12	91

TOTAL CHI SQUARE=

0.80 + 5.27
+ 0.63 + 4.14 = 10.84 SIG at $p < 0.005$

Appendix 6 continued:

TREE N3.

	STICKY	D-VAC	TOTALS
MALE	39 (31.5)	7 (14.5)	46
FEMALE	39 (46.5)	29 (21.5)	68
TOTALS	78	36	114

TOTAL CHI SQUARE=

1.80 + 3.90
\+ 1.22 + 2.64 = 9.55 SIG at $p < 0.005$

TREE S3.

	STICKY	D-VAC	TOTALS
MALE	65 (61.6)	1 (4.4)	66
FEMALE	33 (36.4)	6 (2.6)	39
TOTALS	98	7	105

TOTAL CHI SQUARE=

0.19 + 2.63
\+ 0.32 + 4.45 = 7.58 SIG at $p < 0.01$

TREE N4.

	STICKY	D-VAC	TOTALS
MALE	80 (64.5)	9 (24.5)	89
FEMALE	49 (64.5)	40 (24.5)	89
TOTALS	129	49	178

TOTAL CHI SQUARE=

3.72 + 9.81
\+ 3.72 + 9.81 = 27.06 SIG at $p < 0.005$

TREE S4.

	STICKY	D-VAC	TOTALS
MALE	122 (103.0)	8 (27.0)	130
FEMALE	50 (69.0)	37 (18.0)	87
TOTALS	172	45	217

TOTAL CHI SQUARE=

3.49 + 13.33
\+ 5.21 + 19.92 = 41.96 SIG at $p < 0.005$

Appendix 7: Adult leafhoppers trapped at different heights in apple canopies on two occasions in Orchard 1, 1981-82 season.

1st sample (9 trapping days)

		Height (metres)			
		0.9	1.5	2.1	2.7
Tree 1.	total	603	908	1678	-
	male	174	450	1066	-
	female	429	458	612	-
	others	52	16	17	-
Tree 2.	total	860	958	1817	-
	male	221	502	1187	-
	female	639	456	630	-
	others	35	14	16	-
Tree 3.	total	389	784	1402	-
	male	86	430	981	-
	female	303	354	421	-
	others	72	31	10	-
Tree 4.	total	779	1402	1806	-
	male	228	897	1262	-
	female	551	595	544	-
	others	24	23	8	-
Tree 5.	total	751	760	2421	-
	male	319	453	1836	-
	female	432	315	585	-
	others	30	22	13	-
Tree 6.	total	526	423	1096	-
	male	222	257	851	-
	female	304	166	245	-
	others	44	18	7	-

Appendix 7 continued:

2nd sample (7 trapping days)

		Height (metres)			
		0.9	1.5	2.1	2.7
Tree 1.	total	484	609	1219	1583
	male	326	429	977	1374
	female	158	180	242	209
	others	18	15	3	3
Tree 2.	total	377	437	1125	1670
	male	226	278	894	1432
	female	151	159	231	238
	others	30	9	7	7
Tree 3.	total	445	428	1200	2097
	male	263	274	902	1668
	female	182	154	298	429
	others	9	14	7	0
Tree 4.	total	505	726	1209	1197
	male	275	488	937	1010
	female	230	238	272	187
	others	9	14	7	0
Tree 5.	total	481	707	1227	2269
	male	274	471	968	1853
	female	207	236	259	416
	others	19	9	6	6
Tree 6.	total	447	478	1026	1349
	male	303	339	843	1148
	female	144	139	183	201
	others	40	8	7	4