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CONTRACT REPORT

Biological Control of Damson-hop Aphid on Plum 1994

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Biological Control of Damson-hop Aphid on Plum

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1.0 INTRODUCTION

Aphids are the most serious sucking pests of plum (*Prunus domestica*), and in the UK three potentially damaging species overwinter on a range of both wild and cultivated *Prunus* species; the leaf-curling plum aphid, *Brachycaudus helichrysi*; the mealy plum aphid, *Hyalopterus pruni*; and the damson-hop aphid, *Phorodon humuli*.

All three species will debilitate plum trees through the removal of assimilates, decrease photosynthetic ability and contaminate fruit as a result of sooty mould development on honeydew, and act as potential vectors for a number of important viruses, such as plum pox.

Of the three aphid pests the leaf-curling plum aphid causes the most severe damage, its phytotoxic saliva inducing permanent distortion of the leaves and new growth, and eventual defoliation of those areas colonised by the aphid. The leaf-curling plum aphid is the first of the three species to hatch from overwintering eggs, and subsequent population build-up in the spring can be rapid, often causing significant damage to plum trees before detection and implementation of chemical control measures. The mealy plum aphid only occasionally causes serious problems for growers as its distribution within plum orchards tends to be patchy and localised. The damson-hop aphid is unique among pest aphid species in the UK in having crop plants as both primary and secondary hosts, and thus it is subjected to a similar range of pesticides throughout the spring on plum, and the summer on hop. This has led to an intense selection pressure, and subsequent resistance to all pesticide groups currently registered for use. The absence of an effective pesticide for damson-hop aphid makes it the greatest concern for growers.

In recent years there has been a movement back towards the traditional use of tar oils as dormant sprays against the overwintering eggs of plum aphids. However, field trials have prompted concern over the efficacy of winter washes, which appear more effective in reducing the spring populations of the damson-hop aphid than reducing those of the leaf-curling plum aphid (R. Umpelby, ADAS Worcester, pers. comm.). Two possible reasons are suggested for the apparent lack of efficacy of tar oils against the eggs of leaf-curling plum aphid. The first is that overwintering eggs are unaffected by the spray, either by way of intrinsic resistance or as a result

of sheltered oviposition sites. The second possible reason takes account of the unusually early hatch of this aphid species. Most eggs of the leaf-curling plum aphid hatch before winter washes are applied in November and December, and thus the dormant sprays are being used against an increasingly mobile target.

In spring adequate control of the leaf-curling plum aphid and the mealy plum aphid can still achieved through the use of conventional aphicides. However, the prophylactic use of pesticides against these two aphid species can destroy natural enemies, allowing the build up of pesticide resistant damson-hop aphid.

In order to relieve the selection pressure for resistance, and minimise detrimental side-effects of pesticides on natural enemy populations, an integrated approach to pest management must be developed, employing a range of alternative biological control strategies. The manipulation of pest and natural enemy complexes offer a possible solution.

To manage a pest species properly, population dynamics must be understood, and this can only be achieved through comprehensive monitoring studies in the field. Such studies reveal when aphids are abundant and also give clues as to how they may be managed. Concurrent monitoring of natural enemy populations may reveal which control agents are important in the system, when they act, and when their manipulation may or may not be beneficial in controlling the aphid pest species. In addition, the frequent assessment of a number of sampling techniques will compare their relative efficiency and convenience, evaluating their usefulness as potential field monitoring tools for future monitoring programmes within plum.

With plum aphids there is the opportunity to investigate two main complementary biological control strategies. The first involves augmentation of the aphids' natural enemies. In the present study the effectiveness of predator augmentation will initially be investigated through artificial field-releases of commercially-available green lacewing larvae (*Chrysoperla carnea*), then as further information on pest and natural enemy dynamics within plum are obtained, the feasibility of manipulating the numbers of other potential biocontrol agents will be assessed.

The second biological control strategy to be investigated involves the direct manipulation of plum aphid behaviour through the use of semiochemicals; specifically aphid sex pheromones and their components. At present only the sex pheromone of the damson-hop aphid has been identified following a collaborative study involving HRI East Malling and Rothamsted, and its synthetic production in the laboratory has enabled the integration of the pheromone into field experiments. Studies will assess whether aphid sex pheromone can be used to attract damson-hop aphid autumn migrants and males into traps designed specifically as delivery systems for transmissible entomopathogenic fungi, with the aim of initiating a fungal epidemic among the sexual aphid generations on plum during autumn. In addition the role of aphid sex pheromone in host location by plum aphid parasitoids will be investigated.

1.1 Objectives of first years study

Within the first year there were three main objectives of study;

1. TO IDENTIFY AND STUDY THE IMPACT OF INDIGENOUS NATURAL ENEMIES ON APHID POPULATIONS WITHIN PLUM ORCHARDS.

- Field monitoring of plum aphid populations.
- Collection, identification and monitoring of all predators, pathogens and parasitoids.
- Exclusion cage studies.
- Augmenting aphid numbers/ Prey enrichment.

2. TO INVESTIGATE THE POSSIBILITIES OF DECREASING NUMBERS OF PEST APHID SPECIES THROUGH THE MANIPULATION OF NATURAL ENEMIES.

- Predator release studies.
- Evaluating the infectivity to sexual aphid generations of an entomopathogen in autumn.

3. TO INVESTIGATE THE OPPORTUNITIES FOR INTEGRATION OF APHID SEX PHEROMONE INTO BIOCONTROL STRATEGIES WITHIN PLUM.

- Manipulation of aphid behaviour.
- Manipulation of aphid parasitoid behaviour.

2.0 MATERIALS AND METHODS

2.1 SITE

WM115, HRI East Malling. 14 rows of 21 plum trees, mainly cv. Victoria, interspersed with 54 pollinator trees, cv. Czar. Both varieties were grafted on Pixy rootstocks. The trees were 14 years old, and the orchard had been un-managed for two years. No pesticide treatments had been applied since July 1992, and no pesticides or winter washes were applied during the course of these experiments.

In addition, two unsprayed non-commercial orchards, cvs. Edwards and Marjorie's Seedling, were sampled at Fairbourne Manor Farm, Harrietsham.

2.2 STATISTICAL TREATMENT OF DATA

Data were transformed [$y = \text{Log}_{10}(x + 1)$, where x = untransformed counts] to stabilize variances, and analyzed using ANOVA. The Least Significant Difference (LSD) test was used for means separation at $p<0.05$, when the F statistic for the treatment effect was significant at $p<0.05$.

2.3 FIELD MONITORING OF PLUM APHIDS AND THEIR POTENTIAL NATURAL ENEMIES

The aim of this study was to gain information on the effectiveness of the indigenous aphid natural enemies found in plum orchards. Through the use of various monitoring methods, differences in abundance and phenology of beneficial organisms were highlighted, and attempts were made to relate these findings to plum aphid population levels. A number of concurrent sampling techniques were used in order to interpret effectively the interactions between pests and natural enemies throughout the year.

2.3.1 Monitoring plum aphids

Populations of the three aphid pests were monitored at weekly intervals. Initially 100 randomly-selected first-year shoots were used as an index for egg abundance, and then later in the season

100-leaf samples were used to estimate numbers of active aphids.

2.3.2 Monitoring aphid predators

Predators were monitored at weekly intervals using beating tray samples, and coloured sticky traps (blue, white and yellow). This sampling programme was carried out systematically from mid-April to early-November. Beat sampling was continued throughout the winter at less-frequent intervals. To complement these studies, predator refugia (conventional 1.5 l plastic soft-drink bottles packed with corrugated cardboard) and whole branch analyses were used to monitor beneficial species which overwintered within the plum orchard. The eggs, larvae and adults of predators were also recorded when found in leaf and shoot samples.

2.3.3 Monitoring plum aphid parasitoids

Muslin bands (*c.* 25 x 60 cm.), were tied around the base of numerous aphid-infested branches in order to provide a potential refuge site for parasitized aphids. The species and size of the aphid colonies were noted. The muslin bands were replaced weekly, and their contents recorded.

2.3.4 Monitoring epizootics in plum aphid populations

Dead mycosed aphids were counted in weekly leaf samples, but neither the aphid species attacked nor the disease organism was identified.

2.4 ASSESSING THE SIGNIFICANCE OF NATURAL ENEMIES IN PLUM ORCHARDS

2.4.1 Experiment 94/EX1: The relative impact of birds and insects as aphid predators

Four basic types of exclusion cage were used, ranging in their specificity with regards to the size and habit of the potential plum aphid predators they were designed to exclude.

A. Total exclusion cage - The treatment branch was enclosed in a white polyester net bag (*c.* 100 cm x 60 cm), supported internally by two wire hoops that had been cross-braced onto the branch. The mesh size was small enough to prevent the passage of all the aphid life-stages, and of beneficial insects. Two bands of Oecotak A_5 were spread around the base of the experimental branch to prevent access by all crawling insects.

B. Exclusion of birds and flying insects only - the same basic design as the total exclusion cage, except that Oecotak was not used, and the bag was pegged open at the neck, allowing access to crawling insects.

C. Bird exclusion - 1 m^2 sections of green Netlon polythene mesh (mesh size 15 mm) were folded over the experimental branch and sealed at both ends with nylon string. Oecotak was not used.

D. Exclusion of birds and crawling insects only - the same design as the bird exclusion cage, except that two bands of Oecotak were placed around the base of the experimental branch to exclude all crawling insects.

Two experimental controls were also used. The first was simply an open branch, while the second was an environmental control, where an attempt was made to mimic the properties of the net cages, with respect to light and wind interception.

The experimental design consisted of 6 blocks (where a single tree constitutes a "block"), each containing all the above 6 treatments. In an attempt to counteract the natural variation in plum aphid numbers within and between blocks, all treatment branches were inoculated with five damson-hop aphid nymphs. Weekly samples of five leaves from within each treatment were used to monitor the relative numbers of the various aphid species. Any predators found inside the total exclusion cage were systematically removed, likewise any winged or crawling insects were removed from their respective exclusion cages.

2.5 DECREASING NUMBERS OF PEST APHID SPECIES THROUGH THE MANIPULATION OF NATURAL ENEMIES

2.5.1 Predator release studies

The effect of artificial releases of predatory lacewing larvae on aphid populations was investigated in two ways; firstly within inclusion cages on individual branches, and secondly on whole trees within the plum orchard. In both cases treatments were inoculated with first instar common green lacewing larvae, reared in the laboratory from field collected adults.

2.5.1.1 Experiment 94/PR1: Influence of release of predatory lacewing larvae on aphid population development

Total exclusion cages (see above) were used to enclose each treatment branch. All treatments were inoculated with damson-hop aphid nymphs prior to release of the predators (as above). The experiment used a randomised complete block design, with 6 blocks (where a single tree constitutes a "block"), each containing the four treatments:

A. Nil larvae (control)

B. 2 lacewing larvae

C. 4 lacewing larvae

D. 8 lacewing larvae

At weekly intervals samples of five leaves selected at random were removed from each treatment, and the relative numbers of the various aphid species recorded.

2.5.1.2 Experiment 94/PR2: Release of predatory lacewing larvae onto whole plum trees

A randomised complete block design was used, with two blocks, each of four trees. The following four treatments were each applied to a tree in both blocks:

A. Nil larvae (control)

B. 10 lacewing larvae

C. 20 lacewing larvae

D. 40 lacewing larvae

Treated trees were well separated by untreated guard trees. The four predator treatments were allocated randomly among the four trees in each block. The lacewing larvae were released at the junction between branches and trunk, dispersing from there to the rest of the tree. The trees were not artificially inoculated with aphids. At weekly intervals, a sample unit of five leaves, selected without bias, was removed from each of three different levels; below 1.5 m, between 1.5 m and 2.25 m, and above 2.25 m. Any aphids were identified and counted.

2.5.2 *Verticillium lecanii* as a microbial insecticide of damson-hop aphid in the laboratory and field.

Verticillium lecanii is a well-proven aphid pathogen, and is marketed as a commercial microbial aphicide ("Vertalec") for use within controlled environments such as glasshouses. In this study, the specific pathogenicity of *V. lecanii* for damson-hop aphid, and the spread of infection between

sexual morphs, were investigated. Experiments using aphids inoculated with the fungi were carried out under controlled conditions in the laboratory, and within field cages during autumn. Aphids were "walked" on sporulating plates of *V. lecanii* for 5 minutes to inoculate them with the fungus. Control aphids were walked on blank agar plates.

2.5.2.1 Laboratory study

The pathogenicity of *V. lecanii* was assayed in the laboratory using "walked" and "non-walked" damson-hop aphid autumn migrants. Gynoparae were released singly onto plum leaves (cv. Pixy), maintained within perspex boxes.

2.5.2.2 Field trial

The experimental design consisted of four blocks of a complete factorial design with two treatments (gynoparae and males) at two levels (inoculated and control). Thus, any one block contained the following four treatment combinations:

A. 10 control gynoparae + 10 control males.

B. 10 control gynoparae + 10 inoculated males.

C. 10 inoculated gynoparae + 10 control males.

D. 10 inoculated gynoparae + 10 inoculated males.

The treatment combinations A-D were randomly allocated to four Pixy rootstocks (*c.* 0.8 m high) The trees were cleared of all aphids and potential predators, and then caged with a net exclusion bag. The gynoparae were introduced into the cages on 28.09.94, and the males were introduced 34 days later. The release of the males was determined by their availability.

2.6 INFLUENCE OF SYNTHETIC SEMIOCHEMICALS ON INSECTS WITHIN PLUM ORCHARDS.

The following studies were carried out to determine whether (i) water traps (Figure 1) and louvred traps (Figure 2), releasing damson-hop aphid sex pheromone, would catch male damson-hop aphid within plum orchards, and (ii) the release of aphid sex pheromone components at aphid colonies can increase local levels of parasitism.

2.6.1 Experiment 94/P1: Assessing the practical efficiency of traps releasing damson-hop aphid sex pheromone within plum orchards.

A quasi-complete 8 x 8 randomised block (Latin square) design, with periodic rerandomisation within the block, was used to compare the attractiveness of sex-pheromone-releasing and control, yellow louvred and yellow water traps within plum orchards. Pheromone-releasing traps incorporated vials containing (4a*R*, 7*S*, 7a*S*)-nepetalactol, the sex pheromone of the damson-hop aphid. Three pheromone-releasing and three control louvred traps, plus one pheromone-releasing and one control water trap were used. A thin coat of Oecotak A_5 was spread on the Petri-dish housing the vial containing the pheromone, or control vial, within the louvred trap to capture any attracted aphids. The position of the traps was rerandomised daily, irrespective of catch numbers. All aphids caught were identified to species and sexed. The study was carried out late in the autumn, from 27.10.94 - 01.12.94.

2.6.2 Experiment 94/P2: Use of the aphid sex pheromone component, nepetalactone, to enhance host location by parasitoids in the field.

The semiochemical (+)-(4a*S*, 7*S*, 7a*R*)-nepetalactone is a sex pheromone component for many aphid species, and a known kairomone for some aphid parasitoids (e.g. *Praon* spp.). Vials containing nepetalactone were placed at two heights (above and below *c.* 1.5 m) adjacent to established aphid infestations, during early June. Changes in the levels of parasitism were compared to those on similar control sites. Eight control trees and 8 "pheromone-releasing" trees (where a tree contains a pair of treatments, one high, one low) were randomly distributed around the perimeter of the orchard. After one week, samples of five leaves were removed from each treatment, from within the area of infestation. This was repeated at weekly intervals. The aphid species and approximate population size were also noted. All unparasitized and parasitized aphids were identified, aphid mummies were reared through to adult emergence in order to identify and sex the parasitoids.

3.0 RESULTS AND DISCUSSION

3.1 FIELD MONITORING OF PLUM APHIDS AND THEIR NATURAL ENEMIES

3.1.1 Monitoring plum aphids

3.1.1.1 Overwintering populations

Examination of shoot samples showed an extremely low aphid egg density of one egg per 80 buds. This average egg density was only exceeded on a single occasion during the 20 week sampling period. Although the majority of all plum aphid eggs were deposited in bud axils, their distribution along the shoot varied depending on the species. Eggs of the mealy plum aphid showed a normal distribution over the entire length of the shoot (Figure 3). Conversely, eggs of the leaf-curling plum aphid/damson-hop aphid type showed a skewed distribution, with 95% of oviposition occurring adjacent to the proximal 14 buds (Figure 3). Oviparae are larviposited on the leaf surface, so their initial distribution is probably related to the availability of suitable leaf material. Once oviparae are reproductive they need move only a short distance to the nearest suitable bud to lay eggs. The mealy plum aphid oviposits from mid-August to September, when leaf material suitable for development of oviparae is generally available along the entire length of the shoot. Oviparae of the leaf-curling plum aphid and damson-hop aphid oviposit much later, during October, when progressive leaf senescence from the tip downwards has restricted oviposition to the proximal lateral bud axils.

On most sampling dates non-viable eggs were found, where collapse was either intrinsic (eg. due to infertility) or a result of predation. Although egg mortality in other aphid species has been recorded at levels exceeding 70%, the majority of which is attributed to insect and bird predation, egg densities within the study orchards were too low and fluctuating to assess mortality factors. The only potential predators observed in the orchards were Blue tits, and anthocorid bugs, which were recorded in beat samples up until late November. However, Bullfinches, which removed over 30% of the buds in some orchards (Figure 4), could potentially increase egg mortality by as much as 40% through incidental losses. Thus it is likely that significant egg mortality factors are in operation within plum orchards. Further studies are needed to determine more precisely the extent of this predation, and how widely it fluctuates from year to year.

3.1.1.2 Spring populations

Hatch of leaf-curling plum aphid/damson-hop aphid type eggs was observed from January to mid February. Previous studies have shown that eggs of the leaf-curling plum aphid hatch shortly after oviposition, and hatching is completed by early January while buds are still dormant (cf. Figure 4). With no actual observations of leaf-curling plum aphid egg hatch, no conclusions could be drawn on the timing of eclosion during this study. Build-up and decline of leaf-curling plum aphid populations was rapid and showed markedly fewer fluctuations than those of damson-hop aphid or mealy plum aphid (Figure 5). Peak aphid abundance occurred on 18 May, and was larger than the subsequent peak populations of both damson-hop aphid and mealy plum aphid combined.

The earliest newly hatched larva of damson-hop aphid was observed on 13 January, while plum buds were still dormant. This observation questions the accuracy of forecasting studies which use bud burst of the overwintering host as the phenological indicator for timing the first egg hatch of this aphid species. Damson-hop aphid populations built-up slowly from mid-May, peaked on 1 June, and declined over the following 6 weeks (Figure 5). Hatching of mealy plum aphid eggs was observed from 6 January until the end of March. Build up of aphid numbers was erratic, with the population levels showing three separate peaks; on 4 May, 15 June and 3 August, each followed by a rapid decline in aphid numbers over the subsequent 2-4 weeks. The development of aphid populations on plum in spring followed patterns found in previous studies, where leaf-curling plum aphid, having hatched first, builds up into larger numbers earlier than either damson-hop aphid or mealy plum aphid (Figure 5). The major population decline for plum aphids corresponded well with the period of spring migration, as recorded in previous studies and in Rothamsted Insect Survey (RIS) suction trap data for 1994.

3.1.1.3 Autumn populations

In 1994, autumn populations of damson-hop aphid and leaf-curling aphid were first observed on 14 and 28 September respectively (Figure 5). The timing of autumn migration is in agreement with observations made by previous workers, and suction trap catches at Wye, Kent (RIS data, 1994). No autumn migrants of mealy plum aphid were observed in the experimental plum orchard in 1994.

3.1.1.4 Percentage alatiform

Aphid aggregation can affect the rate of population increase, mainly through intraspecific mechanisms controlling the rates at which apterae multiply and migrant alatae are produced. The rise to peak population density for both damson-hop aphid and leaf-curling plum aphid coincided with an increase in the proportion of alatoid nymphs (Figure 6), once numbers of individuals fall drastically the population begins to compensate by increasing the relative proportion of non-alatoid to alatoid nymphs. However, this is not sufficient to prevent extinction, probably assisted by increasing levels of predation.

3.1.2 Monitoring aphid predators

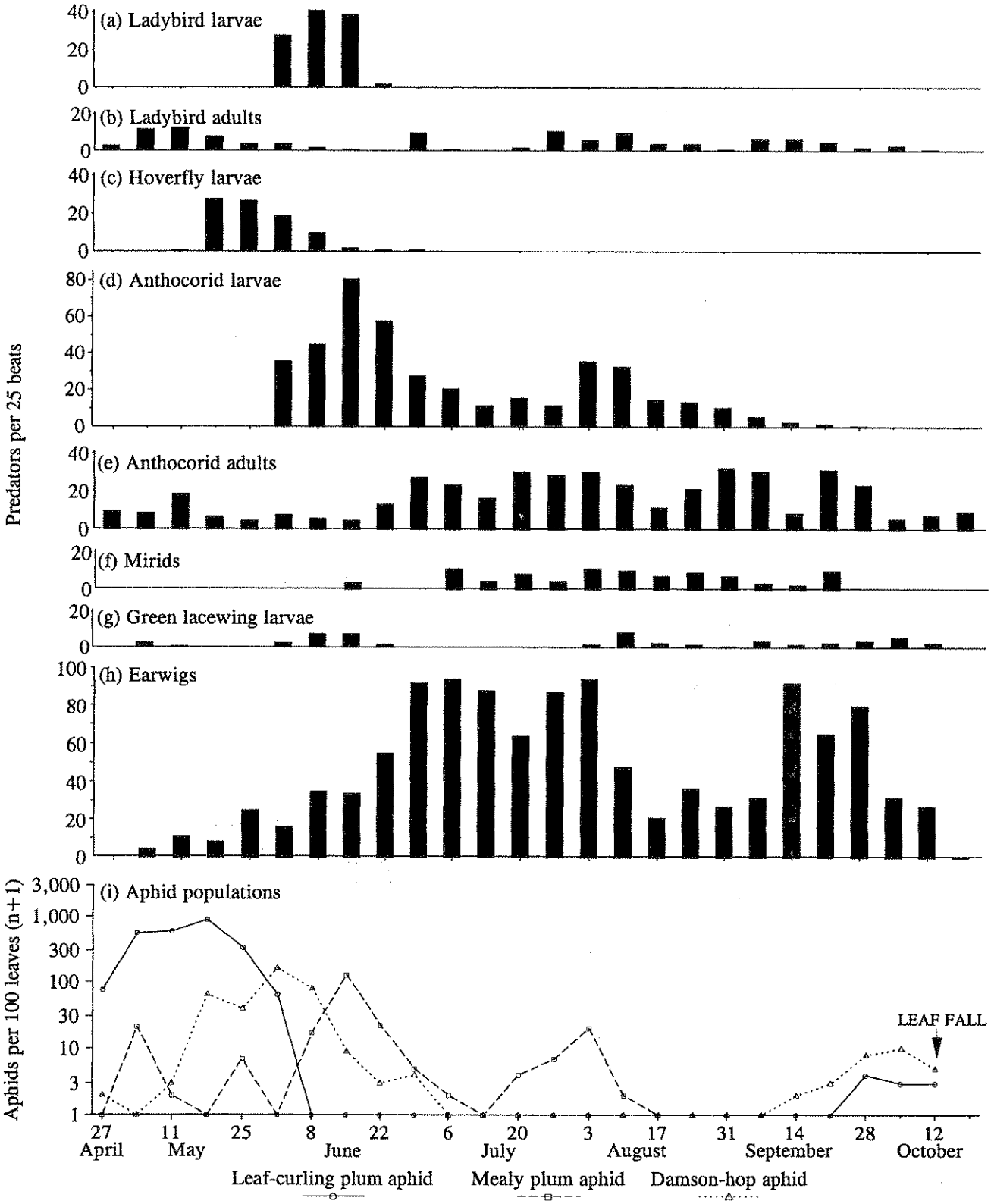
The commonest relatively specific aphid predators in beat samples were anthocorid bugs (Anthocoridae), ladybirds (Coccinellidae), mirids (Miridae) and hoverfly larvae (Syrphidae)(Figure 7a-f). Adult hoverflies, ladybirds and lacewings (Neuroptera: Chrysopidae and Hemerobiidae) were caught most frequently on the sticky traps (Figure 8a-h).

3.1.2.1 Predator populations in autumn

Adult anthocorids and ladybirds, and lacewing larvae, were the most abundant aphidophagous predators during autumn (Figure 7b, d and g). From mid-September to November, female anthocorids (*Anthocoris nemorum*) were the only specific aphid predators that appeared regularly in samples.

Polyphagous predators, including earwigs and spiders, remained abundant during September and October (Figure 7h and k), but their importance as beneficial agents within plum orchards during autumn is questionable. Levels of earwig damage to fruit can often outweigh their beneficial contribution as predators, while spiders may eat other predators, such as anthocorids. However, studies by previous workers have shown the ability of both earwigs and spiders to deplete small populations of aphids during autumn. Considering this, and the relative abundance of earwigs during September and October, and of spiders throughout the year (Figure 7h and k), such polyphagous predators, already present in the orchard when plum aphids start to invade or accumulate, are a potentially useful predatory resource, and may play a particularly important role as predators of the sexual generations of plum aphids.

FIGURE 7. CHANGES IN APHID AND PREDATOR POPULATIONS ON PLUM AT HRI EAST MALLING DURING 1994. (A)-(H), (J) AND (K): WEEKLY COUNTS OF PREDATORS MADE BY BEATING TRAY SAMPLING. (I) CHANGES IN APHID NUMBERS PER 100 LEAVES, DUPLICATED FROM FIGURE 5 FOR PHENOLOGICAL COMPARISON.



Predator refugia contained few overwintering aphidophagous predators, but high numbers of male earwigs. The earwigs showed a significant spatial pattern of occurrence, with a greater proportion in the south-eastern corner of the plum orchard. In this case, the uneven distribution may be due to differential survival of earwigs; the most suitable areas for earwigs arising where feeding sites are more abundant, or high soil moisture lowers egg mortality due to desiccation. Future studies of adult feeding habits, and observations on distribution and contents of nesting sites, may provide the reasons for the uneven distribution of earwigs within orchards, and will establish the importance of the common earwig as a predator of aphids on plum.

3.1.2.2 Predator populations in spring and summer

The anthocorid, *A. nemorum*, the 10-spot ladybird (*Adalia decempunctata* L.) and the 14-spot ladybird (*Propylea quatuordecimpunctata* L.) dominated catches of predatory insects in beating-tray samples (Table 1). The composition of ladybird species found on the trees corresponded closely to the proportions of those caught on sticky traps over the same sampling period. Adult lacewings, also monitored in the early spring using sticky traps, consisted largely of the common green lacewing, *Chrysoperla carnea* (Chrysopidae), and the brown lacewing, *Hemerobius humulinus* (Hemerobiidae)(see Table A2). The predatory larvae of the common green lacewing were regularly found in low numbers in beating tray samples.

Although anthocorids and ladybirds appeared early in the spring, the majority of aphid specific predators only became abundant after the populations of leaf-curling plum aphid had peaked. Thus, decline in populations of the aphids leaf-curling plum aphid and damson-hop aphid, though hastenened by increasing levels of predation, was largely due to other factors such as epizootics, intraspecific competition and the dispersal of alates to secondary hosts. There was synchrony between the build-up of mealy plum aphid populations and increase in specific predator numbers because the late build-up of the pest coincided with the peak populations of predators associated with leaf-curling plum aphid and damson-hop aphid.

TABLE 1. RELATIVE ABUNDANCE (%) OF ANTHOCORID AND LADYBIRD (COCCINELLID) SPECIES SAMPLED USING A BEATING TRAY DURING 1994.

SPECIES	LARVAE	ADULTS
Anthocoridae		
Anthocoris nemorum	77.4	81.8
A. nemoralis	19.5	12.3
Orius spp.[1]	3.1	
O. majusculus		3.4
O. minutus		2.1
O. niger		0.2
A. confusus	0.0	0.2
Total no. of individuals	**430**	**471**
Coccinellidae[1]		
Adalia 10-punctata		34.9
Propylea 14-punctata		33.3
A. 2-punctata		13.2
Coccinella 7-punctata		10.9
Calvia 14-guttata		4.6
Coccinella 11-punctata		3.1
Total no. of individuals	**110**	**129**

[1]Larvae of these taxa were not separated to species.

Previous workers concluded that the voracious larvae of hoverflies were the most important predators of the mealy plum aphid. In this study adult hoverflies from 23 species with predatory larvae were caught on sticky traps (see Table AII.2). The most numerous adult hoverflies with predatory larvae known to be associated with aphid colonies (see Table AII.2), occur from late June to August (Figure 8d-g), when mealy plum aphid was still abundant in the orchard (Figure 5). Hoverflies are potentially effective aphid predators. The adults respond rapidly to increases in prey abundance, and discriminate between aphid colonies - selecting only the most suitable sites for egg-laying. Blue sticky traps were particularly attractive to the most abundant hoverfly species, *Episyrphus balteatus*. Colour also influenced catches of other predatory species, with yellow traps significantly more attractive than blue or white for the 2-spot ladybird (*A. bipunctata*) and 14-spot ladybird (*Propylea quatuordecimpunctata*), and the anthocorid, *Anthocoris nemorum*. Both yellow and blue are clearly important visual stimuli

predators within plum orchards. Further work is needed to establish the strength of visual cues, and whether they interact with other stimuli such as aphid honeydew, aggregation or sex pheromones released by aphid prey, or plant damage volatiles resulting from aphid feeding.

The visual ecology of plum aphid predators needs further study, not only so that appropriate visual stimuli can be incorporated into traps for population monitoring, but also to assess the feasibility of managing orchard margins and ground cover to increase predator abundance, as demonstrated with hoverflies in an arable agro-ecosystem. In order to complement such studies, the fauna of windbreaks associated with plum orchards needs investigation. For example, the alder aphid (*Pterocallis alni*) can provide a good alternative food supply for developing predators of orchard pests. In the present study the highest densities of the aphidophagous brown lacewing *Hemerobius humulinus* and mirid *Malacocoris chlorizans* were found in the south-western corner of the orchard, which is adjacent to the alder windbreak, and the first part of the orchard to intercept the prevailing wind. Future monitoring of aphid natural enemies will extend to neighbouring alder windbreaks.

Sticky trap catches also highlighted differences in the sex ratios of certain predators in flight, catching significantly more female than male hoverflies of *E. balteatus* and *Melanostoma mellinum*, and more female than male mirids (*Malacocoris chlorizans*).

Numerous eggs of the predatory mirid *M. chlorizans*, were found on shoots and branches. In contrast to the oviposition sites of aphids, the majority of mirid eggs were found in cracks and under loose bark of the older tree growth (Table 2).

TABLE 2. OVIPOSITION SITES FOR THE PREDATORY MIRID *Malacocoris chlorizans* ON PLUM TREES.

	No. of eggs[1]		% eggs on Lateral branches
	Lateral branches	Extension growth	
BRANCH A	24	4	86
BRANCH B	15	4	79

[1]Where Extension growth represents shoots less than one year old, and Lateral branches growth that is older than one year.

Plum aphids and their natural enemies do not form a closed system. Predators may spend one or more generations elsewhere, only preying on plum aphids for part of the year. Many of the mid-to-late season predators among the hoverflies, ladybirds and mirids, may spend at least one generation in other habitats, feeding on different prey before moving into the plum orchard. It follows that the degree of biological control of aphids depends to an unknown extent upon the habitats and prey species surrounding the orchard, and that by manipulating nearby plant species and/or orchard ground cover, one might improve biocontrol prospects.

3.1.3 Monitoring plum aphid parasitoids

The use of muslin bands at sites of aphid infestation highlighted distinct differences in the distribution of parasitized plum aphids on trees. Of the 438 aphid mummies collected during the experiment, 71% were *Ephedrus* spp. parasitoids within damson-hop aphid hosts, and 98% of these were found off the foliage within muslin bands (Table 3). In the absence of muslin bands, aphids would normally mummify in sheltered sites on trees, such as in bark crevices, where they are easily overlooked. The concealed position of many plum aphid mummies has undoubtedly led to underestimation of the importance of parasitoids.

Of the adult *Ephedrus* spp. parasitoids that emerged in the laboratory over 85% were *E. persicae*. This reflected earlier observations where nearly 80% of emerged wasps from mummies on damson-hop aphid and leaf-curling plum aphid hosts were also *E. persicae*. Previous workers have observed *E. persicae* to be an important parasitoid of leaf-curling aphids in woodland and orchard habitats. This habit suggests that *E. persicae* may also be of particular benefit in a biocontrol strategy for the leaf-curling aphid in plum orchards.

Approximately 95% of the aphid mummies found on foliage were of *Praon* spp., the commonest host for this parasitoid being mealy plum aphid (Table 3).

Aphids parasitized by *Praon* spp., unlike *Ephedrus* spp., were most common in aphid colonies on the lower leaf surfaces. *Hyalopterus pruni* was also parasitised by *Aphidius* spp., whose mummies were found exclusively in the bands (Table 3).

TABLE 3. PLUM APHID PARASITOIDS: A COMPARISON OF APHID MUMMY ABUNDANCE AND MUMMIFICATION SITE.

	JUNE	JULY				AUGUST	
	29	6	13	20	27	3	10
Associated aphid spp.	**No. muslin bands tied per week**						
Damson-hop aphid	14	13	11	8	6	0	0
Mealy plum aphid	9	9	5	4	3	5	7
No. of aphid mummies							
***Ephedrus* sp.** on damson-hop aphid							
ON MUSLIN BAND	140	85	69	20	0	0	0
ON FOLIAGE	0	0	0	0	5	0	0
***Ephedrus* sp.** on mealy plum aphid - NOT OBSERVED							
***Praon* sp.** on damson-hop aphid							
ON MUSLIN BAND	0	0	0	0	0	0	0
ON FOLIAGE	0	0	0	0	3	0	0
***Praon* sp.** on mealy plum aphid							
ON MUSLIN BAND	0	0	0	0	4	7	0
ON FOLIAGE	0	0	0	1	3	43	54
***Aphidius* sp.** on damson-hop aphid - NOT OBSERVED							
***Aphidius* sp.** on mealy plum aphid							
ON MUSLIN BAND	0	0	1	3	0	0	0
ON FOLIAGE	0	0	0	0	0	0	0

The abundance of both *Ephedrus* and *Praon* spp. mummies appears to be more closely related to the population levels of their preferred host species (damson-hop aphid and mealy plum aphid, respectively), than to the availability of suitable mummification sites. Using the muslin band technique, developed in this study, more comprehensive assessments of the levels of parasitism in plum aphids can now be made.

3.1.4 Significance of entomopathogens

Natural populations of plum aphids may become heavily infected with fungal pathogens, particularly Entomophthoraceae. The pattern of occurrence for entomopathogenic fungal infection found in this study was similar to that observed by previous workers, where infection was prevalent between early May and early July, with a peak of infection around early June (Figure 9). The fungal pathogens were associated largely with colonies of leaf-curling plum aphid and damson-hop aphid, indeed, Figure 9 shows a rapid decline in the numbers of leaf-curling plum aphid around the time of peak infection. Caution must be exercised when extrapolating such results to gain an impression of exactly how important entomopathogenic infections are as mortality factors for these aphid species. This is because diseased individuals accumulate, whereas uninfected individuals may disperse, a situation further complicated when aphids mummify in crevices and under bark where their numbers are easily overlooked. However, mummification within sheltered sites may be largely responsible for perpetuating the infection of aphids with Entomophthoraceae. in the following spring. Previous workers found that all infected aphids sampled from bark crevices contain resting spores of the fungus.

3.2 USE OF PREDATOR EXCLUSION CAGES TO ASSESS THE SIGNIFICANCE OF NATURAL ENEMIES

A rapid early build up of leaf-curling plum aphid caused damage and defoliation within many treatment cages, hampering interpretation of the results. However, important trends were apparent; the numbers of damson-hop aphid were lowest in treatments where there was greatest access for predators (Table 4), and for both aphid species the exclusion of birds appears to correspond with an increase in aphid numbers, suggesting the possible important role of birds as predators. Modification of this experiment is needed, in an attempt to reduce the disruptive knock-on effects that can exist within pest complexes. It may be necessary to use selective pesticides in order to isolate an individual aphid species, and thereby assess specific predator impact.

TABLE 4. THE EFFECT OF VARIOUS LEVELS OF PREDATOR EXCLUSION ON BUILD UP OF APHIDS ON PLUM*.

TREATMENT	LOG (n+1) MEAN APHID COUNTS[1]	
	Damson-hop aphid	**Leaf-curling plum aphid**
Uncaged control	2.21[a]	3.08[a]
Bird exclusion cage	3.83[a]	4.59[a]
Bird and flying insect exclusion cage	2.77[a]	3.21[a]
Bird and crawling insect exclusion cage	3.94[a]	2.57[b]
Total exclusion cage (control)	3.34[a]	1.32[b]
Environmental control cage	1.38[a]	1.97[b]
SED (0.05)	1.522	0.915

* Summary of 14 weekly records.

[1] Means subtended by the same letter are not significantly different ($p<0.05$), by an LSD test.

3.3 DECREASING NUMBERS OF APHID PEST SPECIES THROUGH MANIPULATION OF NATURAL ENEMIES

3.3.1 Predator release studies

3.3.1.1 Experiment 94/PR1: Influence of release of predatory lacewing larvae on aphid population development.

Defoliation of 42% of the experimental branches by leaf-curling plum aphid reduced the number of available replicates. Analysis of the remaining replicates showed that increasing the numbers of released lacewing larvae results in a corresponding decrease in the numbers of damson-hop aphid (Table 5). No trend was apparent for leaf-curling plum aphid.

Further controlled field studies need to be undertaken, releasing increased numbers of chrysopid larvae in order to achieve a significant depletion in numbers of the targeted aphid species.

TABLE 5. THE EFFECT OF PREDATOR AUGMENTATION WITH GREEN LACEWING LARVAE ON APHID POPULATION DEVELOPMENT ON PLUM, WITHIN INCLUSION CAGES *.

TREATMENT	LOG (n+1) MEAN APHID COUNTS[1]	
(No. released larvae per cage)	**Damson-hop aphid**	**Leaf-curling plum aphid**
0 (control)	6.50	2.61
2	6.06	2.31
4	5.85	1.61
8	5.55	2.53
SED (0.05)	1.629	1.626

* Summary of 13 weekly records.
[1] Treatment means not significantly different ($p<0.05$).

3.3.1.2 Experiment 94/PR2: Release of predatory lacewing larvae onto whole plum trees.

There was no correlation between the numbers of predators released, and the corresponding population densities of either damson-hop aphid or leaf-curling plum aphid (Table 6). For both aphid species more aphids were recorded from the 1.5 - 2.25 m sampling height (Table 7). This difference in spatial distribution of the aphids within the tree was significant for leaf-curling plum aphid only ($p<0.05$), which was present in higher numbers than damson-hop aphid.

TABLE 6. THE EFFECT OF PREDATOR AUGMENTATION WITH GREEN LACEWING LARVAE ON APHID POPULATION DEVELOPMENT ON WHOLE PLUM TREES*.

TREATMENT	LOG (n+1) MEAN APHID COUNTS[1]	
(No. released larvae per tree)	**Damson-hop aphid**	**Leaf-curling plum aphid**
0 (control)	1.20	3.26
10	1.70	3.43
20	0.88	3.75
40	1.34	3.69
SED (0.05)	1.040	0.345

* Summary of 10 weekly records.
[1] Treatment means not significantly different ($p<0.05$).

TABLE 7. THE DISTRIBUTION OF LEAF-CURLING PLUM APHID AND DAMSON-HOP APHID POPULATIONS ON PLUM TREES*.

	LOG (n+1) MEAN APHID COUNTS[1]	
SAMPLING HEIGHT	**Damson-hop aphid**	**Leaf-curling plum aphid**
< 1.5m	1.44[a]	2.89[a]
1.5-2.25m	1.47[a]	4.28[b]
>2.25m	0.95[a]	3.43[a]
SED (0.05, 0.01)	0.900	0.299

* Summary of 10 weekly records.
[1] Means subtended by the same letter are not significantly different ($p<0.05$), by an LSD test.

The sample unit of 5 leaves/sampling height/tree was inadequate for highlighting the effects of increasing predator density on aphid numbers, as a result, aphids were absent from many sample units. This experiment should be repeated, using a more comprehensive, preferably non-destructive, sampling method, and experimental trees that have been artificially inoculated with aphids to augment the natural populations.

3.3.2 *Verticillium lecanii* as a microbial insecticide of damson-hop aphid in the laboratory and field

3.3.2.1 Laboratory study

The aphicidal potential of *V. lecanii* was confirmed; 38% of inoculated damson-hop aphid gynoparae died within 48 hours, and 75% within 8 days, all deaths due to mycosis as evidenced by sporulation on the surface of cadavers. After 4 days, 6% of oviparae had also died as a result of epizootic infection (Table 8).

Previous studies have shown that damson-hop aphid gynoparae larviposit the majority of oviparae within 48 hours of their final moult. With possibly 40% mortality occurring among inoculated gynoparae, by way of epizootic infection, within the same time period, there is potential for a significant reduction in the numbers of resulting oviparae. The laboratory studies also showed that transmission of *V. lecanii* occurred from damson-hop aphid gynoparae to their oviparous offspring.

TABLE 8. TRANSMISSION OF VERTICILLIUM LECANII BETWEEN INOCULATED DAMSON-HOP APHID AUTUMN MIGRANTS AND THEIR OVIPAROUS OFFSPRING ON PLUM, UNDER CONTROLLED CONDITIONS[1].

Treatment		**Time after inoculation (hours)**					
		48	96	144	192	240	288
Inoculated gynoparae	Total	8	4	4	2	1	1
	No. dead	4	0	2	1	0	0
	Cumulative % epizootics	**38**	**38**	**63**	**75**	**75**	**75**
Oviparous offspring	Total	33	35	34	24	21	16
	No. dead	0	2	10	3	5	2
	Cumulative % epizootics	**0**	**6**	**6**	**6**	**6**	**6**
Control gynoparae	Total	10	10	8	7	6	5
	No. dead	0	2	1	1	1	0
	Cumulative % epizootics	**0**	**0**	**0**	**0**	**0**	**0**
Oviparous offspring	Total	28	35	35	32	31	30
	No. dead	0	0	3	1	1	1
	Cumulative % epizootics	**0**	**0**	**0**	**0**	**0**	**0**

[1] 20°C, 10:14 L:D.

3.3.2.2 *Field trial*

Infection with *V. lecanii* accounted for 92% of deaths among inoculated gynoparae recovered from the field. Table 9 shows that inoculation of gynoparae reduces final ovipara production by nearly 50%. Inoculation of males prior to introduction into the field had no significant effect on either numbers of oviparae, or resulting eggs, but it was not possible to assess whether eggs were contaminated with spores. The present field studies have shown that transmission of the entomopathogen is possible under autumnal weather regimes. Indeed it seems that the impact of the entomopathogen on the aphid population was amplified by additional stresses not present

under laboratory conditions, such as the weather. Aphid cadavers showing *V. lecanii* sporulation were collected from the leaves of inoculated treatments in the field cages. If they remain on the host plant, it is possible that such aphids may serve as sources of infection in the following spring. Further studies are required to establish quantitatively the extent of disease transmission between the different aphid morphs (including ovipara to egg), and under different conditions.

TABLE 9. EFFECTS OF *Verticillium lecanii* ON AUTUMN GENERATIONS AND EGG PRODUCTION OF DAMSON-HOP APHID ON PLUM, IN THE FIELD.

Treatment		Mean no. oviparae/ gynopara	Mean no. ova/ ovipara
Gynopara	Control	1.60	2.56
	Inoculated	0.79	1.68
Male	Control	1.20*	2.04
	Inoculated	1.19*	2.20

* Male treatments do not affect oviparae production, but means are included for completeness.

3.4 INFLUENCE OF SEMIOCHEMICALS ON INSECTS WITHIN PLUM ORCHARDS

3.4.1 Experiment 94/P1: Assessing the practical efficiency of traps releasing damson-hop aphid sex pheromone within plum orchards

Three aphid species were caught in high numbers: the damson-hop aphid; the bird-cherry oat aphid (*Rhopalosiphum padi* L.), and the blackberry-cereal aphid (*Sitobion fragariae* Walker).

Male damson-hop aphid were found exclusively within pheromone-baited traps, providing the first conclusive evidence that the sex pheromone is attractive to aphids within an orchard of the aphid's primary host, *Prunus* spp. (Table 10). Furthermore, the strength of the attraction was sufficient to draw significant numbers of male damson-hop aphid into louvred traps and onto a dish which in future experiments will contain a culture of entomopathogen.

TABLE 10. TOTAL NUMBER OF APHIDS CAUGHT IN PHEROMONE-RELEASING [(4a*R*, 7*S*, 7a*S*)-nepetalactol] AND CONTROL, YELLOW PETRI DISH WATER TRAPS AND LOUVRED TRAPS PLACED WITHIN A PLUM ORCHARD DURING AUTUMN (27.10.94-01.12.94).

Aphid species	Water traps		Louvred traps	
	Control	Pheromone	Control	Pheromone
Damson-hop aphid	0	41♂	0	21♂
Bird-cherry oat aphid	152♂50♀	2317♂307♀	0	15♂
Blackberry-cereal aphid	27♂	2♂	0	0

Experiments using these traps within hops (Campbell, pers. comm.) have shown that, in the absence of Oecotak glue, male damson-hop aphid eventually disperse from the trap. Laboratory experiments (see above) have shown that damson-hop aphid gynoparae, inoculated with *V. lecanii*, can transmit the pathogen to its offspring. Preliminary field trials (see above) have shown that transmission of *V. lecanii* in this way can reduce final ovipara production by nearly 50%. It is not yet known whether inoculated males can transmit the pathogen to oviparae during copulation. Further studies are also needed to determine whether inoculation of aphids with fungal spores impairs flight activity and mate location.

The preliminary results indicate that live-traps of this type might provide the means to disseminate fungal pathogens among the oviparous aphid population, and thus provide a novel strategy for improving IPM of damson-hop aphid, and potentially other aphid pests, in plum.

3.4.2 Experiment 94/P2: Use of an aphid sex pheromone component, nepetalactone, to enhance host location by parasitoids in the field

Release of the aphid sex pheromone component, nepetalactone, in the immediate vicinity of aphid colonies had no apparent effect on the level of parasitism, as monitored by leaf sampling, when compared to control colonies. Considering the findings of this study concerning the location of aphid mummies on plum (see section 3.1.3) this experiment needs to be repeated using the muslin band method.

4.0 CONCLUSIONS

1. **In unsprayed plum orchards, extremely low aphid egg densities of less than 15 eggs/1000 buds can lead to an aphid infestation in spring exceeding an average 10 aphids/leaf.**

2. **Aphid populations on plum during spring follow a clear pattern, where leaf-curling aphid, having hatched first, built-up into larger numbers earlier than either damson-hop aphid or mealy plum aphid. Subsequent decline of aphid populations is largely due to intraspecific competition and the dispersal of alates to secondary hosts.**

3. **The lack of synchrony between build-up of aphid populations and increase in numbers of beneficial insects results in the inability of predators to reduce aphid populations significantly.**

4. **Concealed mummification sites of many parasitized plum aphid has undoubtedly led to previous underestimation of the importance of parasitoids. In future studies the use of muslin bands will allow a more comprehensive assessment of parasitism in plum aphids.**

5. **Artificial releases of green lacewing larvae can result in decreases in aphid numbers, though to achieve significant reduction in aphid numbers it will be necessary to increase the numbers of predators released.**

6. **Inoculation with *Verticillium lecanii* results in death of damson-hop aphid gynoparae due to mycosis, under both controlled and autumnal field conditions. Inoculated gynoparae are capable of transmitting lethal doses of *V. lecanii* to their oviparous offspring.**

7. **Damson-hop aphid sex pheromone is attractive to male hop aphids within plum orchards. The attraction is strong enough to draw significant numbers of males into traps designed to inoculate aphids with entomopathogen, but samples of the pheromone were available too late to assess their effect on gynoparae.**

4.1 Timetable of work for Year 2

1. Expand the comprehensive monitoring programme (leaf samples, beating tray and sticky traps) within the plum orchard to include direct observation of predator activity throughout the day, and monitoring studies on the fauna within adjacent alder windbreaks.

2. Eliminate populations of leaf-curling plum aphid and mealy plum aphid at field experiment sites, using predator-friendly selective aphicides (e.g. Pirimicarb), in order to isolate populations of damson-hop aphid for targeted studies.

3. Repeat predator exclusion experiments at treated field sites (see above), expand to include "open" exclusion treatments, where predators are hand-removed from open branches.

4. Repeat predator release studies within cages and on whole trees, increasing size of lacewing release in order to achieve significant reductions in aphid numbers.

5. Continue studies manipulating parasitoid behaviour with aphid sex pheromone components. Use the muslin band technique to monitor the levels of parasitism.

6. Evaluate the voracity of the most abundant predators in controlled environment studies.

7. Further field and laboratory studies with sexually-transmitted entomopathogen.

8. Install and compare the efficiency of a number of predator refugia designs.

9. Repeat "prey enrichment" experiment.

10. Identify and assess field mortality factors for overwintering aphid eggs within plum orchards.

Glossary

Alate: having wings

Alatiform/Alatoid: a nymph which will eventually moult to an alate adult, identified by the presence of wing buds, which are usually only visible in the 3rd or 4th instar.

Apterous: wingless

Autumn migrants: in heteroecious aphids, alate parthenogenetic females which migrate between the secondary and primary host (=gynoparae).

Entomopathogen: any disease organism growing on or in insects.

Epizootic: a rapidly spreading disease affecting a large number of animals throughout a large area.

Fundatrigeniae: the progeny of the fundatrix.

Fundatrix: parthenogenetic female developing from a fertilized egg.

Gynopara: a parthenogenetic female which produces oviparae. In heteroecious aphids, gynoparae move to the primary host in autumn.

Heteroecious: having an annual alternation between primary and secondary hosts.

Kairomone: a substance produced, acquired by or released as the result of the activities of an organism which, when it contacts an individual of another species in the natural context, invokes in the receiver a behavioral or physiological reaction adaptively favourable to the receiver but not the emitter.

Morph: an adult phenotype of a species that is morphologically (and/or reproductively) distinct from another phenotype of that species.

Mummy: 1. empty skin of a parasitized aphid, containing or surmounting the cocoon of a parasitic wasp. **2.** a shrivelled, dry cadaver that results from the effects of fungal infection.

Mycosis: any infection or disease caused by a fungus.

Nymph: a juvenile form without wings or with incomplete wings in insects with incomplete metamorphosis.

Ovipara: the sexual female morph of an aphid which mates with males and lays eggs.

Parasitoid: an animal, especially an insect, that is parasitic during the larval stage of its life cycle but becomes free-living when adult.

Parthenogenesis: reproduction by development from unfertilized eggs, producing offspring which are genetically identical to the parent.

Phenology: recording and study of periodic events, as of flowering, mating, migration, etc., in relation to climactic and other factors.

Pheromone: a substance that is secreted by an organism to the outside and causes a specific reaction in a receiving organism of the same species

Primary host: the plant on which the sexual phase of the life cycle and egg laying occurs.

Proximal: situated towards the point of attachment of a branch.

Secondary host: in heteroecious species, the plant on which only parthenogenetic reproduction takes place.

Semiochemicals: a chemical involved in the interaction between organisms.

Spring/Primary migrants: winged parthenogenetic females migrating from primary to secondary host.

TABLE AI.1. PREDATORY ARTHROPODS CAUGHT USING BEATING TRAY SAMPLING WITHIN A PLUM ORCHARD AT HRI, EAST MALLING (20/04/94 - 02/11/94).

SPECIES	TOTAL CATCH	MAX. CATCH/25 BEATS	MEAN CATCH/ 25 BEATS/ CATCHING PERIOD	
ARACHNIDA				
ANYSTIDAE	257	60	14.3	[18]
SPIDERS	2063	176	71.1	[29]
COLEOPTERA				
CANTHARIDAE	3	1	<1	[12]
CARABIDAE				
Demetrias atricapillus	21	5	1.3	[16]
Dromius meridionalis	1	1	<1	[1]
D. notatus	3	2	1	[3]
COCCINELLIDAE	110(i)	41	27.5	[4]
Adalia bipunctata	17	3	<1	[22]
A. decempunctata (f. bimaculata)	1	1	<1	[1]
A. decempunctata (f. decempunctata)	39	8	1.4	[28]
A. decempunctata (f. decempustulata)	5	3	1.7	[3]
Calvia quattuordecimguttata	6	3	<1	[22]
Coccinella septempunctata	14	3	<1	[16]
C. undecimpunctata	4	3	<1	[15]
Propylea quatuordecimpunctata	43	9	1.9	[23]
STAPHYLINIDAE				
Tachyporus obtusus	3	2	<1	[11]
DERMAPTERA				
Forficula auricularia	840	92	32.3 27.3	[36]
DIPTERA				
SYRPHIDAE*	89(i)	28	11.1	[8]
Eupeodes corollae	1♀	1♀	1♀	[1]
Platycheirus albimanus	1♀	1♀	1♀	[1]

Where (i) = larval form. All individuals were sexed where possible. *Adults not predatory.

TABLE AI.1. CONT. PREDATORY ARTHROPODS CAUGHT USING BEATING TRAY SAMPLING WITHIN A PLUM ORCHARD AT HRI, EAST MALLING (20/04/94 - 02/11/94).

SPECIES	TOTAL CATCH	MAX. CATCH/25 BEATS	MEAN CATCH/ 25 BEATS/ CATCHING PERIOD	
HEMIPTERA				
ANTHOCORIDAE				
Anthocoris confusus	1♀	1	1	[1]
A. nemoralis	11♂	3♂	<1♂	[21]
	47♀	10♀	2♀	[23]
	84(i)	21	7.6	[11]
A. nemorum	135♂	16♂	5.2♂	[26]
	250♀	27♀	10.9♀	[29]
	333(i)	61	18.5	[18]
Orius majusculus	3♂	2♂	<1♂	[5]
	13♀	4♀	<1♀	[24]
O. minutus	10♀	3♀	<1♀	[14]
O. niger	1♂	1♂	1♂	[1]
Orius sp. larvae	13	8	2.6	[5]
MIRIDAE				
Blepharidopterus angulatus	1♀	1♀	1♀	[1]
Campyloneura virgula	12	5	2	[6]
	6(i)	2	1	[6]
Deraeocoris lutescens	6♂	5♂	2♂	[3]
	19♀	6♀	3.2♀	[6]
	13(i)	5	2.2	[6]
Heterotoma merioptera	1(i)	1	1	[1]
Phytocoris dimidiatus	5♀	2♀	<1♀	[7]
P. reuteri	5♀	3♀	1.7♀	[3]
	5(i)	4(i)	1.7(i)	[3]
Pilophorus perplexus	1♀	1♀	1♀	[1]
Malacocoris chlorizans	2♂	1♂	<1♂	[6]
	24♀	6♀	3.4♀	[7]
	2(i)	2(i)	2(i)	[1]
REDUVIIDAE				
Empicoris vagabundus	1♂	1♂	1♂	[1]

Where (i) = larval form. All individuals were sexed where possible.

TABLE AI.1 CONT. PREDATORY ARTHROPODS CAUGHT USING BEATING TRAY SAMPLING WITHIN A PLUM ORCHARD AT HRI, EAST MALLING (20/04/94 - 02/11/94).

SPECIES	TOTAL CATCH	MAX. CATCH/25 BEATS	MEAN CATCH/ 25 BEATS/ CATCHING PERIOD	
NEUROPTERA				
CHRYSOPIDAE				
Mallada flavifrons	1(i)	1	1	[1]
M. ventralis[1]	12(i)	3	<1	[24]
*Chrysoperla carnea**	3♂	1♂	<1♂	[22]
	16♀	4♀	<1♀	[26]
	30(i)	8	2.3	[13]
Chrysopidia ciliata[1]	2(i)	1	<1	[4]
*Cunctochrysa albolineata**[1]	17(i)	4	2.1	[8]
*Nineta flava**	3(i)	2	<1	[5]
*N. vittata**	1(i)	1	1	[1]
HEMEROBIIDAE				
Hemerobius humulinus	4♂	1♂	<1♂	[8]
	7♀	2♀	<1♀	[17]
H. lutescens	1♂	1♂	1♂	[1]
	3♀	2♀	<1♀	[1]

Where (i) = larval form. All individuals were sexed where possible.
*Adults known to be non-predatory.
[1]Third larval instar usually carries coat of debris.
Catching period (no. of weeks) in parentheses.

TABLE AII.1. PREDATORY INSECT CATCHES ON COLOURED STICKY TRAPS PLACED WITHIN A PLUM ORCHARD AT HRI, EAST MALLING (18/04/94 - 07/11/94).

	STICKY TRAP COLOUR					
	Blue		White		Yellow	
COLEOPTERA						
CANTHARIDAE						
Rhagonycha fulva (?)	7		13		16	
COCCINELLIDAE						
Adalia bipunctata	4		5		19	
A. decempunctata	7		12		35	
Calvia quattuordecimguttata	1				2	
Coccinella septempunctata					1	
Propylea quatuordecimpunctata	2		2		32	
Stethorus punctillum	2					
STAPHYLINIDAE						
Unidentified species	1		2		2	
Tachyporus sp.	3		6		6	
DERMAPTERA						
Forficula auricularia	4		1		1	
HEMIPTERA						
ANTHOCORIDAE						
Anthocoris nemoralis		1♀		1♀		
A. nemorum	4♂	3♀	4♂	7♀	18♂	37♀
(Orius sp.)			2♂		3♂	2♀
MIRIDAE						
Blepharidopterus angulatus	4♂	1♀	1♂		1♂	
Campyloneura virgula				3♀		5♀
Heterotoma merioptera			11		1	
Malacocoris chlorizans	192♂	3♀	315♂	5♀	337♂	13♀
Phytocoris dimidiatus		1♀			1♂	2♀
P. reuteri						1♀
P. tiliae		2♀			1♂	

Where (i) = larval form. All individuals were sexed where possible.

TABLE AII.1 CONT. PREDATORY INSECT CATCHES ON COLOURED STICKY TRAPS PLACED WITHIN A PLUM ORCHARD AT HRI, EAST MALLING (18/04/94 - 07/11/94).

	STICKY TRAP COLOUR					
	Blue		White		Yellow	
NEUROPTERA						
CHRYSOPIDAE						
Mallada ventralis				1♀		
Chrysopa perla		1♀				1♀
*Chrysoperla carnea**	10♂	17♀	10♂	17♀	19♂	22♀
*Nineta vittata**		1♀				
HEMEROBIIDAE						
Wesmaelius betulinus					1♂	
Hemerobius humulinus	3♂	11♀	6♂	8♀	13♂	14♀
H. lutescens	2♂	1♀	2♂	3♀		5♀
Micromus variegatus		1♀		1♀		3♀

Where (i) = larval form. All individuals were sexed where possible.
*Adults not predatory.

TABLE AII.2. HOVERFLY CATCHES ON COLOURED STICKY TRAPS PLACED WITHIN A PLUM ORCHARD AT HRI, EAST MALLING (18/04/94 - 07/11/94).

Species with predatory larvae	STICKY TRAP COLOUR					
	Blue		White		Yellow	
SYRPHINAE						
BACCHINI						
*Melanostoma mellinum**	29♂	32♀	10♂	11♀	1♂	
(where m = melanic)	26♀(m)		13♀(m)		2♀(m)	
*M. scalare**	4♂	7♀	3♂	2♀	1♂	2♀
*Platycheirus albimanus**	12♂	10♀	5♂	4♀	2♂	
*P. clypeatus**	1♂		1♂			
P. discimanus		2♀				
P. manicatus	4♂	4♀	1♂	2♀		
P. peltatus	20♂	39♀	15♂	24♀		1♀
P. scutatus	2♂	7♀	1♂	4♀		
SYRPHINI						
*Chrysotoxum festivum***	1♂	3♀				2♀
*Dasysyrphus albostriatus***		1♀				
Epistrophe eligans					2♂	3♀
E. nitidicollis			2♂			
Episyrphus balteatus	160♂	287♀	85♂	115♀	27♂	30♀
Meliscaeva auricolis	2♂	2♀				
Eupeodes corollae	49♂	29♀	21♂	14♀	10♂	4♀
E. latifasciatus		3♀	1♂	1♀	1♂	
E. luniger	1♂	1♀	1♂			
Scaeva pyrastri				2♀		
Sphaerophoria (scripta?)	2♂	10♀	2♂	4♀	2♂	2♀
S. ribesii	19♂	14♀	6♂	6♀	8♂	10♀
Syrphus vitripennis	11♂	3♀	4♂	3♀	9♂	4♀
*Xanthogramma pedissequum***		3♀		1♀		
MILESIINAE						
PIPIZINI						
Pipiza noctiluca		7♀	1♂	6♀		1♀

* Adults common but larvae are rarely seen at aphid colonies.
** Unconfirmed as aphidophagous predators.

Contract between HRI (hereinafter called the "Contractor") and the Horticultural Development Council (hereinafter called the "Council") for a research/development project.

1. TITLE OF PROJECT **Contract No: SF/30**
Contract date: 4.11.93

BIOLOGICAL CONTROL OF DAMSON-HOP APHID ON PLUM

2. BACKGROUND AND COMMERCIAL OBJECTIVE

The damson-hop aphid is becoming increasingly difficult to control with pesticides on commercially grown plum. That is because the same pesticides are applied against aphids on both plum and on hop, the damson-hop aphids sole summer host, resulting in a uniquely severe pressure for selecting individual aphids resistant to those pesticides. On pesticide-treated crops only the most resistant aphids can survive and multiply. In autumn, sexual reproduction between pesticide-resistant individuals gives rise to individuals that, in the following spring, combine the pesticide-resistance mechanisms of their parents. Since the mid-1960's the aphid has successively developed resistance to organo-phosphates, carbamates, and most recently to synthetic pyrethroids. Recent experience from UK and elsewhere in Europe suggests a useful life for a completely new pesticide group of less than ten years. Once resistance develops to one product within a group then it quickly extends to other pesticides with a similar chemistry.

MAFF-funded strategic work at East Malling has shown that the damson-hop aphid can be controlled on hop biologically, using a combination of naturally-occurring enemies topped up by a release of commercially-available predatory lacewings. Similar biological control studies have been reported against aphid pests of tree fruits elsewhere in Europe and in the USA. In addition, current work at East Malling with the recently-identified and synthesised sex pheromone of damson-hop aphid promises new opportunities for disrupting the aphid's life-cycle on plum.

The commercial objective is to assess the possibility of achieving biological control of damson-hop aphid on plum by combining naturally-occurring enemies (augmented if necessary by release of predatory lacewings), with disruption of sexual reproduction in autumn.

3. POTENTIAL FINANCIAL BENEFIT TO THE INDUSTRY

Naturally-occurring aphid enemies are abundant in the mixed farming landscape of the UK. Exploitation of this neglected resource for aphid control on plum, either as a stand-alone technique or with other components of biological control, would lead to a reduction of pesticide use, and break the cycle of pressures selecting aphids resistant to aphicides. Other plum-inhabitating species of aphids would also be expected to be controlled by natural

enemies.

4. SCIENTIFIC/TECHNICAL TARGET OF THE WORK

Assess the impact of naturally-occurring enemies on population development of damson-hop aphid.

Evaluate the necessity of augmenting naturally-occurring enemies with a release of lacewings.

Assess methods for using synthetic sex pheromone to disrupt mating by damson-hop aphid.

Evaluate the enhancement of predator populations in plum orchards by provision of overwintering refugia.

5. CLOSELY RELATED WORK - COMPLETED OR IN PROGRESS

MAFF-funded strategic work at HRI East Malling under projects G03B-2, G08A-2 and G09B concentrate on natural enemies of top fruit, soft fruit and hops. A MAFF-Industry link-funded project is examining the feasibility of exploiting the damson-hop aphid synthetic sex pheromone. It includes infecting aphids with a pathogen that would be transmitted during mating. This existing project and the current proposal would be co-ordinated so that the impact of the epizootic strategy may be monitored. Techniques developed under these projects will be used in the proposed work.

6. DESCRIPTION OF THE WORK

The impact of the naturally-occurring enemies on damson-hop aphid population development from egg-hatch in spring would be studied in the field. The effect of augmenting naturally-occurring enemies with a release of lacewings would be investigated. Natural enemies would be identified and their relative importance assessed. Methods used would include direct observation, suction-trapping, pheromone trapping, beating, predator exclusion, and feeding experiments in controlled-environment rooms.

Mating disruption would be studied using synthetic sex pheromone. The impact on egg-laying and egg-viability of an entomopathogen carried to plum by female migrant and male aphids from hops would be assessed in the field and in controlled-environment studies.

The possibility of enhancing predator populations in plum orchards would be investigated using artificial refugia.

Timetable:

Year 1 - Conduct replicated field experiment assessing impact of naturally-occurring enemies on aphid population development from

egg-hatch.

- Collect and identify all predators, pathogens and parasitoids.
- Prepare and install predator refugia in plum orchards.
- Assess disruptive potential of synthetic sex pheromone on mate-finding by male aphids in laboratory/controlled environment experiments.
- Investigate infectivity to egg-laying female aphids of an entomopathogen transported by males.

Year 2
- Evaluate voracity of most-abundant predators in controlled environment studies.
- Collect and inspect samples of refugia, renewing all those removed.
- Repeat field experiment assessing impact of naturally-occurring enemies expanded, if necessary, to include release of lacewings.
- Continue studies of mating disruption using sex pheromone.
- Further small-scale studies with sexually-transmitted entomopathogen.

Year 3
- Depending on results in first two years, modify and continue field experiments on impact of natural enemies.
- Collect and inspect contents of all refugia.
- Complete any unfinished voracity studies.
- Depending on results of laboratory studies and on availability of sufficient quantities of sex pheromone, conduct field experiments on mating disruption.

7. COMMENCEMENT DATE DURATION AND REPORTING

Start date: 1 October 1993; duration 3 years. Annual reports will be produced in October 1994 and 1995 and a final report detailing the results obtained during the three years of the project will be produced 01.10.96.

8. STAFF RESPONSIBILITIES

Project Leader: Dr C A M Campbell
Other staff: Postgraduate student (new appointment)

9. LOCATION

HRI East Malling.

10. COSTS

Year 1	Year 2	Year 3
£15,298	£16,062	£16,865

Total = £48,225

11. PAYMENT

On each quarter day the Council will pay to the Contractor in accordance with the following schedule:

Quarter/Year	1993	1994	1995	1996
1	-	3825	4016	4216
2	3824*	3824	4015	4216
3	-	3825	4016	4216
4	-	4015	4217	-

* This payment was made before the start of the contract and it covers the work done in quarter 4, 1993.

Contract No: SF/30

TERMS AND CONDITIONS

The Council's standard terms and conditions of contract shall apply.

Signed for the Contractor(s)

Signature.....

Position.....

Date.....

Signed for the Contractor(s)

Signature.....

Position.....

Date.....

Signed for the Council

Signature.....

Position.....

Date.....