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The results and conclusions in this report are based on one survey and a series of small-scale experiments. The conditions under which the studies were carried out and the results have been reported with detail and accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with the interpretation of the results especially if they are used as the basis for commercial product recommendations.

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Authentication

I declare that this work was done under my supervision according to the procedures described herein and that this report represents a true and accurate record of the results obtained.

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PRACTICAL SECTION FOR GROWERS

Background and objectives

The predatory mirid bug, *Macrolophus caliginosus,* was originally reared for control of whiteflies, but has been found to attack a wide range of pest species. It has been released in UK tomato crops under DoE license for two full growing seasons and has provided a useful contribution to the overall IPM programme. However, in the latter half of the 1996 season some tomato growers became concerned that the predator was causing direct damage to their plants. An HDC funded project began to investigate this subject in April 1997. The scientific objectives were:

1. To determine the mechanism by which *M. caliginosus* damage tomato plants.
2. To identify the most important factors contributing to *M. caliginosus* damage to tomatoes.
3. To devise a means of managing *M. caliginosus* populations in tomato crops that will optimise pest control with minimal plant damage.

Specific targets for the first year were:

1. To organise a survey to determine the commercial significance of *M. caliginosus* damage.
2. To catalogue damage symptoms.
3. To identify the factors that influence damage.
4. To monitor survival of *M. caliginosus* between tomato crops.

Summary of Results

Ten round, eight cherry and one cherry plum tomato crops were included in the survey to determine the commercial significance of damage caused by *M. caliginosus.* All were selected following detection of the predators during routine crop monitoring. Several types of damage

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were recorded in cherry and round tomato crops and confirmed in small scale experimental studies:

- **Leaf damage** – *M. caliginosus* feed on leaves resulting in distorted growth. This was observed in all the monitored cherry tomato crops and in 40% of the round tomatoes but is thought not to affect yield.
- **Failed set** - *M. caliginosus* feed on flowering trusses causing premature flower drop and reduced fruit set. This damage was seen in every monitored cherry tomato crop and in 30% of round tomatoes.
- **Fruit damage** – *M. caliginosus* occasionally feed on developing fruit causing scarring and down grading.

In the most extreme case, a cherry tomato grower estimated losses attributable to *M. caliginosus* to be equivalent to £3000 per 1000 m^2.

M. caliginosus built up to large numbers following pest outbreaks, sometimes reaching over 300 per plant. The plant damage increased after the invertebrate prey populations had declined. All the monitored crops that suffered damage had over 50 *M. caliginosus* per plant but this should not be considered to be a definitive threshold. There are several factors that influence damage and the threshold will probably vary depending on the precise combination that occur at any time. The following factors are known to be important:

- Number of *M. caliginosus.*
- Availability and type of invertebrate prey.
- Timing and rates of release of *M. caliginosus.*
- Tomato type/cultivar.
- Environmental conditions, including pesticides applied against other pests and diseases.

Many growers who had suffered damage in 1996 decided not to release *M. caliginosus* in their crops in 1997. However, *M. caliginosus* recolonised many of the new crops and some of the worst damage in 1997 occurred where the predators had not been released since the previous season. Monitoring work within this project has shown that *M. caliginosus* can

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survive between crops in the empty glasshouse. Furthermore, live *M. caliginosus* adults and nymphs have been found on weeds outside the glasshouse until at least late December. These over-wintering studies are continuing until April 1998.

During 1997, many tomato growers resorted to one or two sprays of a broad spectrum insecticide to reduce *M. caliginosus* populations. The use of non-specific chemicals reduced *M. caliginosus* numbers and prevented further damage, but often had an adverse effect on other components of the integrated pest management (IPM) programme and biological pollination by bumble bees.

There is little doubt that *M. caliginosus* can make an important contribution to the IPM programme in UK tomatoes if populations can be manipulated to avoid injury to plants and subsequent financial loss to the grower. This project will continue to seek methods of regulating *M. caliginosus* populations that are compatible with other biological control agents. Meanwhile the risk of serious damage to cherry tomatoes is probably unacceptable.

Action points

1. Growers are advised against introducing *M. caliginosus* in cherry tomato crops as there is a strong probability that crop damage will occur.

2. To reduce the risk of *M. caliginosus* surviving between crops, control measures should include both spray treatments in the empty glasshouse and eradication of weeds (particularly nettles and thistles) in the immediate vicinity of the glasshouse.

3. *M. caliginosus* can cause economic damage to round tomato crops but little has been observed where there have been less than thirty *M. caliginosus* per plant or where there has been ample invertebrate prey. To predict the actual risk, growers must assess both the numbers of predators and the availability of prey.

4. Although *M. caliginosus* populations grow primarily in response to the availability of invertebrate prey, the risk of damage to crops can probably be reduced by delaying release of the predators until April and by releasing less than 0.25 per m^2.

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5. If *M. caliginosus* survive between crops, there is an increased risk of plant damage because growers have no control over the size of the initial population. It is therefore sensible to wait to see whether the predators become established naturally before releasing more in the crop.

Recommendation for further research and development work

Following discussions with representatives of the Tomato Growers Association, two priorities for future research and development have been identified:

- To develop an IPM compatible control measure for *M. caliginosus.*

- To develop methods of manipulating *M. caliginosus* populations to obtain the benefits of effective pest control while minimising the harmful effects on plants.

The following research programme has been planned within a limited annual budget:

1998/99

- Identification and evaluation of IPM compatible control measures, eg pymetrozine and entomopathogenic fungi.
- Small-scale studies to determine the relative performance/damage of *M. caliginosus* on specific cultivars of cherry, cherry plum, beefsteak and standard round tomatoes in the absence of pests.

1999/00

- Small scale studies to determine how variables such as environmental conditions, prey type, prey availability and plant condition influence *M. caliginosus* performance/damage on the same range of tomatoes.

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- Formulation of a strategy to maximise benefits of *M. caliginosus* whilst minimising plant damage.

2000/01

Crop scale evaluation of a strategy to maximise benefits of *M. caliginosus* while minimising plant damage.

Practical and financial benefits from the study

M. caliginosus could make a considerable contribution to IPM programmes in tomato crops if populations could be manipulated to avoid injury to plants and subsequent financial loss for the grower.

Evidence already exists that *M. caliginosus* can survive between crops and growers who have released the predator in the past may have to continue to live with the consequences of its presence. To avoid damage, these growers must be able to manage *M. caliginosus* populations effectively.

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EXPERIMENTAL SECTION

INTRODUCTION

The predatory mirid bug, *Macrolophus caliginosus,* was originally reared for control of whiteflies, but has been found to attack a wide range of pest species. It has been released in UK tomatoes under DoE licence for two full growing seasons and has provided a useful contribution to the overall IPM programme. However, in the latter half of the 1996 season some tomato growers became concerned that the predator was causing direct damage to their plants (Hayman and Jacobson, 1996; Sampson, 1996).

The damage was observed initially when large (over 100 per plant) populations of *M. caliginosus* occurred. Such populations were not uncommon following periods of hot weather during which the bugs had a ready supply of invertebrate prey. The main types of damage observed were leaf distortion, which was not thought to affect yield, and premature flower and fruit drop that affected yield. In 1996, two cherry tomato growers sprayed insecticides to reduce numbers of *M. caliginosus* and fruit set improved following treatment, but the effects could have been coincidental.

In the 1997 season, many growers decided not to release *M. caliginosus* in their crops until the risks were properly evaluated. However, *M. caliginosus* populations survived between crops at several sites and large numbers developed despite none being released.

It was important to determine the precise conditions that lead to plant damage to see whether populations of *M. caliginosus* could be manipulated to provide good pest control without significant injury to plants. Factors that were thought to influence plant damage included:

1. Number of *M. caliginosus*
2. Availability of prey
3. Type of prey

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4. Plant condition (e.g. vigour)
5. Tomato type/cultivar
6. Environmental conditions
7. Chemical treatments, including pesticides and foliar feeds.

There were too many possible interactions to investigate in replicated experiments at the start of the project because the study would have been prohibitively expensive. Therefore the number of possible factors were narrowed by monitoring the development of symptoms in selected commercial crops with a view to aiding the design of more focused experiments in the future.

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OBJECTIVES

The overall objective of this project was to improve the knowledge of the mechanism and effects of *M. caliginosus* feeding on tomato plants as a first step in optimising pest control strategies based on this predatory bug.

The scientific and technical targets for the project were:

1. To determine the mechanism by which *M. caliginosus* damage tomato plants.
2. To identify the most important factors contributing to *M. caliginosus* damage to tomato plants.
3. To devise a means of managing *M. caliginosus* populations in tomato crops which will optimise pest control with minimal plant damage.

Specific targets for the first year of the project were:

1. To organise a survey to determine the commercial significance of *M. caliginosus* damage and identify gaps in existing knowledge.
2. To catalogue symptoms of *M. caliginosus* damage to tomato plants.
3. To identify factors that may influence *M. caliginosus* damage to tomato plants.
4. To monitor the survival of *M. caliginosus* within greenhouses between crops.
5. To monitor the survival of *M. caliginosus* outside greenhouses and the invasion of new crops.
6. To increase grower awareness of the damage caused by *M. caliginosus* through an article in "HDC News".

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PART 1 - SURVEY OF *M. CALIGINOSUS* AND ASSOCIATED DAMAGE TO TOMATO CROPS ON COMMERCIAL NURSERIES

Materials and Methods

Between May and October 1997, Derek Hargreaves, Gerry Hayman and Clare Sampson assessed and recorded *M. caliginosus* activity in tomato crops during routine advisory visits to commercial nurseries in Northern England, Southern England and Jersey respectively. Data were collected from eight cherry tomato crops, ten round tomato crops and one cherry plum tomato crop. At each assessment, the number of *M. caliginosus* per plant, their position on the plant, the availability of invertebrate prey and the presence of damage symptoms, were recorded. In addition, notes were made to describe the environmental conditions, recent chemical treatments and any other factors that may have contributed to damage by *M. caliginosus*. To standardise recording procedures, data were compiled on monitoring sheets (Appendix 1) which were returned to HRI, Stockbridge House for analysis. The total numbers of records included in the tables of results in this report are variable because some of the returned monitoring sheets were incomplete.

Numbers of *M. caliginosus* and damage to tomato trusses were assessed more frequently at one nursery following applications of the broad spectrum insecticide, heptenophos (Hostaquick). This began in week 30, when the first signs of damage were observed, and continued in weeks 32, 34, 35, 36 and 39.

At the end of the season, growers who had observed damage were asked to estimate the economic impact of damage which they attributed *M. caliginosus*.

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Results and Discussion

The survey was designed to identify trends that would help to direct future investigation of the factors that influence damage to tomato crops by *M. caliginosus*. The results have been interpreted with caution because there may have been differences in the techniques used by individual surveyors. Furthermore, assessments could not be done systematically but had to coincide with advisory visits and this sometimes led to a lack of continuity in the records.

1.1. *M. caliginosus* establishment

The numbers of *M. caliginosus* per plant that were estimated during site visits are shown in Table 1. Populations of *M. caliginosus* became established in all the monitored crops in which the predators had been released in 1997, and in five monitored crops in which they had not been released since 1996. The population structure was similar on all the different tomato types and the proportion of nymphs to adults was relatively consistent throughout June and July (65:35). In August and September, applications of Hostaquick disrupted the population structure at some nurseries resulting in a greater proportion of nymphs for at least two weeks after the treatments.

The distribution of *M. caliginosus* on tomato plants is shown in Table 2. The predators were found at all levels on the plants but they were most numerous in the middle section and least common on the lowest leaves, particularly at the end of the season. Both adults and nymphs were recorded on the leaves, flowers and fruits of cherry tomato plants. Cast skins were observed on the calyx of the flower/fruit and predators were often observed feeding under the calyx and on the pedicel. In the monitored round tomato crops, *M. caliginosus* were only recorded on leaves but they have been observed on round tomato flowers and fruit on other occasions. *M. caliginosus* were also observed on the mainstems, particularly in the evening or early morning.

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Table 1: *M.caliginosus* release strategies, numbers of *M. caliginosus* per plant and dates of Hostaquick treatments in monitored crops.

Variety	Date released	Release rate	Location	Week Number																							Hostaquick applied in
				19	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	
Cherry tomatoes																											
Favorita	2 April	$0.59/m^2$	Jersey							7			60		60		3	22	0.5			1					Wk 34, 35
Favorita	2 April	$0.44/m^2$	Jersey							3			50		20		4	8	5			2					Wk 34
Favorita	2 April	$0.45/m^2$	Jersey							4			50		20		4	8	5			0.5					Wk 34
Favorita	Not released	0	IOW			11				50				163													Wk 27
DRC 151	Not released	0	IOW							4				154													Wk27
Favorita	28 January	$1/m^2$	Yorks		43			42			100	95	100					36				62				7	Wk 29, 30
Favorita	February-March	$1/m^2$	Sussex	5	15	40					120					4								10			Wk 31
Favorita	Mid-February	$0.5/m^2$	Sussex	5		14		25				50								10		10					Wk 31, 32
Round tomatoes																											
Solairo	1 April	$0.3/m^2$	Jersey							0.1																	
Solairo	February-March	$1/m^2$	Jersey			0.4					15								5								
Solairo	1 April	$0.5/m^2$	Jersey								10																
Solairo	4 April	$1/m^2$	Jersey										30														
Solairo	Early March	$0.5/m^2$	Yorks		2						30		30													24	
Solairo	February-March	$1/m^2$	Yorks													98		25								20	Wk 34
Espero	End February	$1/m^2$	Yorks			20		19																			
Ferrari	Not released	0	Yorks					6					29									25					
Pronto	Not released	0	Yorks												9												
3347	Not released	0	Yorks															2.5									Wk 31
Cherry Plum tomatoes																											
Santa	2 April	$0.72/m^2$	Jersey							0.1			1		1			3	5								

Table 2: Distribution of *M. caliginosus* on tomato plants

Position on plant	Presence of *M. caliginosus* on various parts of round and cherry tomato plants: (expressed as a percentage of all assessments)	
	round tomato (16 asssessments)	cherry tomato (26 assessments)
Lower level	25 %	46 %
Middle level	100 %	100 %
Upper level	81 %	96 %
Leaves	100 %	100 %
Flowers	0 %	50 %
Fruit	0 %	35 %

The *M. caliginosus* populations followed a common growth pattern at most nurseries; building up slowly at the beginning of the season, peaking in July and August, then declining from September. The following factors influenced the time and size of the peak of population growth:

M. caliginosus release date

The dates that *M. caliginosus* were released in crops were compared to the numbers of predators recorded at the peak of population growth. This comparison was based on observations in cherry tomato crops that had similar pest populations during the summer. It is difficult to draw firm conclusions because some data sets are incomplete but there was a clear trend; *M. caliginosus* reached larger populations when released earlier in the year.

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In fact, the largest numbers of *M. caliginosus* were observed in crops where none had been released. It is assumed that these predators invaded the crops immediately after planting so that the populations built up over the longest period of time.

M. caliginosus release rate

M. caliginosus release rates were compared to the numbers on plants when the populations peaked during the summer. Where tomato types and pest numbers were similar, the predators built up to larger numbers when released at higher rates. However, the initial introduction rate appeared to have less influence on the final size of the predator population than did the tomato type and availability of invertebrate prey.

Tomato type / cultivar

Table 3 shows the average number of *M. caliginosus* per plant on three different types of tomato plants, both in week 30 and at the peak of population growth. At the peaks of population growth, *M. caliginosus* numbers were greatest on cherry tomato plants and least on cherry plum tomato plants, with round tomatoes in between. Although only one cherry plum crop was monitored in the survey, the small numbers of *M. caliginosus* found were consistent with observations made in two other crops of the same cultivar in other parts of the country.

Table 3: *M. caliginosus* numbers on different types of tomato plants

Type/cultivar of tomato	**Mean numbers of *M. caliginosus* per plant:**	
	In week 30	**At the peak of population growth**
Cherry (cv Favorita)	65	163
Round (cv Solairo)	30	98
Cherry Plum (cv Santa)	1	5

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Pest populations and pest species

In table 4, *M. caliginosus* activity is related to the occurrence of four important pest species. There was a correlation between the numbers of *M. caliginosus* at the peak of the predator's population growth and the pest infestations in the crops four to six weeks previously.

The largest numbers of *M. caliginosus* were observed on cherry tomato crops, which also had the largest numbers of pests. The smallest numbers of both *M. caliginosus* and pests were observed on the cherry plum tomato crop, even though this crop was surrounded by cherry tomatoes that were heavily infested with *M. caliginosus* and leaf miners.

The species of invertebrate prey appeared to influence *M. caliginosus* population growth. The largest numbers of *M. caliginosus* and the most serious plant damage were recorded following infestations of leaf miners and whiteflies. The predators were less prevalent following spider mite outbreaks, although *M. caliginosus* damage was observed in some patches of spider mite activity. This is consistent with studies in France that have shown that the predator lays ten times more eggs when feeding on whiteflies than on spider mites (Fauvel et al., 1987).

The effects of prey type on the behaviour of *M. caliginosus* were examined in more detail in small-scale experiments (Part 2 of this report).

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Table 4: Relationship between *M. caliginosus* activity and the occurrence of four important pest species.

Nursery and tomato type	Numbers of:				*M. caliginosus* activity	
	Leaf miners	Whiteflies	Spider mites	Leaf Hoppers	Number at population peak	Plant damage recorded?
1-Cherry	Numerous	Moderate	Few		60	Yes
2-Cherry	Numerous				50	Yes
3-Cherry	Numerous	Few			50	Yes
4-Cherry	Numerous		Numerous		154	Yes
5-Cherry	Few	Few			163	Yes
6-Cherry	Numerous		Few		100	Yes
7-Cherry	Few	Few	Moderate	Few	>50	Yes
8-Cherry	Numerous	Few	Numerous	Few	120	Yes
1-Round	Few			Few	-	No
2-Round	Numerous	Few	Moderate		>50	Yes
3-Round	Few	Few	Few	Few	-	No
4-Round	Numerous	Few	Few	Few	30	No
5-Round		Few	Numerous		30	No
6-Round			Numerous		20	No
7-Round	Moderate		Few		28	No
8-Round			Moderate		9	No
9-Round		Few			98	Yes
10-Round	Few		Few		-	No
11-C.Plum	Few	Few			5	No

- Insufficient data

1.2. Damage caused by *M. caliginosus*

Damage symptoms

The type and frequency of *M. caliginosus* damage recorded on the monitored round and cherry tomato crops are summarised in Table 5. The symptoms mentioned can be described as follows:

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Leaf distortion:	Feeding on leaf petioles and leaf veins resulted in distortion as the leaves grew; the tips often being turned downwards.
Leaf necrosis:	Patches of dead tissue were observed on leaves where the vascular tissue had been damaged.
Flower damage:	Distinct feeding punctures were observed through the anther cone, sometimes penetrating the stigma or young fruit. In such cases, flowers failed to set. This type of damage was easily overlooked as the flowers dropped prematurely.
Premature flower/fruit drop:	Where *M. caliginosus* fed on pedicels, flowers or young fruit, the pedicels were weakened and usually broke at the abscission point. This is commonly described as "knuckling off".
Fruit surface:	*M. caliginosus* occasionally fed on the surface of swelling fruit causing small scars which were often in a curved pattern.

Table 5: Incidence of the different types of *M. caliginosus* damage.

Types of Damage	Percentage of tomato crops in which the various types of *M. caliginosus* damage were recorded:	
	Round Tomatoes (10 crops)	Cherry Tomatoes (8 crops)
Leaf disortion	40%	100%
Leaf necrosis	20%	75%
Flower damage	0%	88%
Failed set	30%	100%
Premature flower/fruit drop	20%	100%
Fruit surface scarring	0%	13%

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There was more damage of all types on the cherry tomato crops than the round tomato crops. No damage was recorded on the cherry plum tomato crop.

The leaf distortion and leaf necrosis were unlikely to have affected yield. The most significant damage occurred when flowers failed to set, or when flowers/fruit dropped prematurely (knuckling off). These symptoms were recorded in all eight cherry tomato crops and in three of the ten round tomato crops. The greater incidence of failed set and premature flower/fruit drop on cherry tomatoes corresponded to the *M. caliginosus* activity recorded on the trusses of those crops (page 15).

Damage threshold

Table 4 shows the numbers of predators at the peak of population growth at all the monitored sites and indicates whether damage was recorded. There was a clear trend towards increased damage where there were more predators. Numbers of *M. caliginosus* peaked at over fifty per plant at all the sites where damage was recorded. No plant damage was observed where numbers of *M. caliginosus* remained below thirty per plant. However, the latter should not be considered to be a definitive threshold because there are so many other factors that may influence *M. caliginosus* behaviour.

Time of damage

The first record of plant damage in 1997 was in the first week of June and was in a cherry tomato crop. Damage was recorded at another site in mid-July and at the remainder of sites from mid-August.

At all the sites where damage was observed, *M. caliginosus* had built up to large numbers following a pest infestation. The damage was usually observed four to six weeks after the pests had been controlled which left a large population of predators without invertebrate prey.

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1.3. Economic losses attributed to *M. caliginosus*

Six growers attempted to quantify the financial implications of *M. caliginosus* activity in their crops and expressed their losses as follows:

Cherry tomato crop in southern England – "The level of damage was estimated to be approximately £12,000 per acre. This was based on comparisons with yield in the previous two seasons."

Cherry tomato crop in southern England – "Yields were reduced by 17% over a five week period compared to a similar adjacent block of the same variety."

Cherry tomato crop in Jersey – "Half a truss was lost over a three week period. However, this effect was masked by other changes in crop management, which resulted in an overall increase in yield compared to the two previous seasons."

Cherry tomato crop in northern England – "A total loss of four fruit per plant, estimated to be equivalent to 2.5 to 4 tons of fruit over the whole nursery."

Round tomato crop in northern England – "Damage was observed over a four week period and peaked at 20% of fruit lost. There was also an increase in class 2 fruit from 3.5% to 5.5%. However, overall yields were up from the previous year due to the installation of a new boiler."

Round tomato crop in northern England – "Damage was patchy within affected blocks, with the worst patches corresponding to spider mite "hot spots". Within affected blocks, a complete truss may have been lost in the worst patches, with no damage in other areas. Overall yield was reduced from the previous season, although *M. caliginosus* was not the only cause."

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1.4. Control of *M. caliginosus*

Several growers applied sprays of Hostaquick to control *M. caliginosus* in late July. A series of two sprays prevented the occurrence of further damage, despite some *M. caliginosus* surviving in the crops. Where the damage occurred later in the season, a single spray was adequate.

The effects of Hostaquick treatments on *M. caliginosus* were monitored in more detail in two cherry tomato crops in Jersey. Two high volume sprays were applied to the top third of the plants in one crop (Figure 2), while one spray was applied to an adjacent crop (Figure 3). The sprays did not eradicate the predators but the numbers were reduced and there was little new damage during the remainder of the growing season.

At two of the monitored sites, growers attempted to reduce *M. caliginosus* numbers while minimising the impact on other components of the IPM programme by only spraying part of the crop with Hostaquick. One grower treated every fourth row of plants and the other sprayed only the lower half of the plants. However, neither technique was successful and both crops were subsequently sprayed throughout.

High volume (750 ml product per 1000m^2) and ultra-low volume (32.5 ml product per 1000 m^2) sprays of Hostaquick were compared against *M. caliginosus* in one round tomato crop. The latter was applied with an Enbar sprayer. Ten days after treatment, there were 26 and 7 *M. caliginosus* per plant in the crops sprayed HV and ULV respectively.

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Figure 2 : Weekly counts of the numbers of *M. caliginosus* and damaged fruit per plant before and after 2 treatments of Hostaquick in a cherry tomato crop

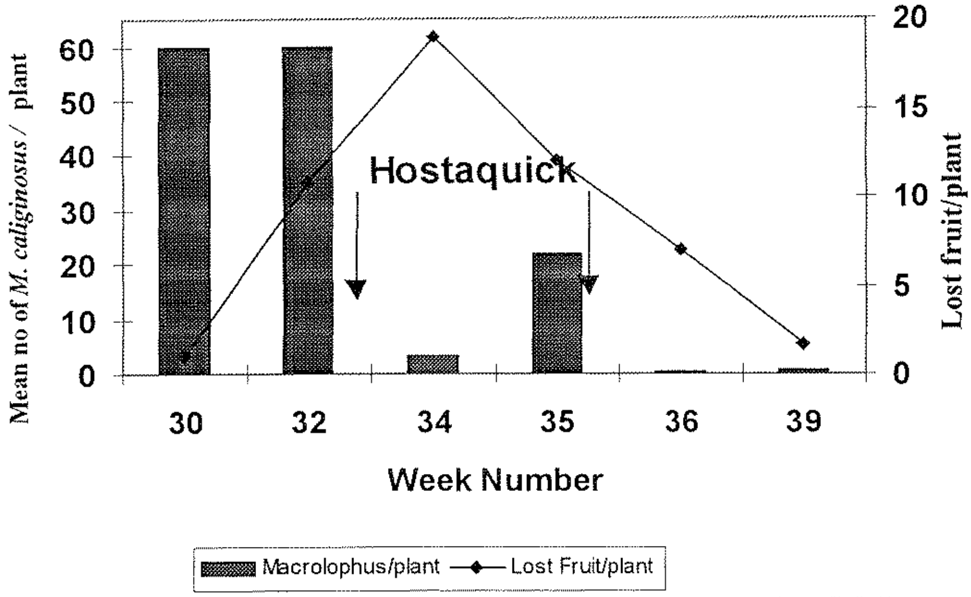
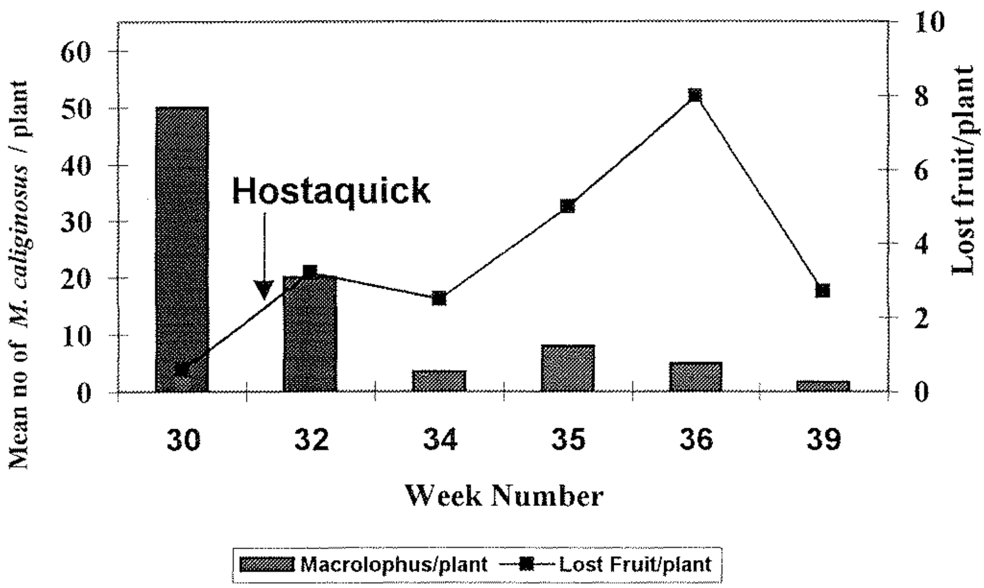


Figure 3 : Weekly assessments of the numbers of *M. caliginosus* and damaged fruit per plant before and after one treatment of Hostaquick in a cherry tomato crop



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PART 2 – SMALL SCALE STUDIES

2.1. Video record of *M. caliginosus* feeding on a tomato truss

Materials and Methods

A tomato truss, still attached to the plant (cv Spectra), was enclosed in a transparent container constructed at the base of a microscope. The latter was fitted with a video camera linked to a video recorder. A single adult female *M. caliginosus* was released in the container and filmed for three hours. The procedure was repeated four times replacing the *M. caliginosus* and plant on each occasion.

Results and discussion

M. caliginosus was observed and filmed feeding on both tomato flowers and pedicels. The predator penetrated the anther cone of the flower and damaged the ovary/young fruit within. It probed at the abcission point on the pedicel and on one occasion fed continuosly for over ten minutes. The damaged flowers became detached at the abcission point.

2.2. The effect of invertebrate prey type on subsequent *M. caliginosus* damage

Materials and Methods

Two batches of *M. caliginosus* were reared from eggs to adults on diets of either Mediterranean flour moth (*Ephestia kuehniella*) eggs, or tomato leaf miner (*Liriomyza bryoniae*) larvae.

Thirty flowering trusses on growing tomato plants (cv Criterium) were enclosed in fine mesh cages and a further ten trusses of similar age were marked for use as untreated

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controls. Ten replicates were prepared of each of the following four treatments:

1. 10 adult female *M. caliginosus* from the moth egg culture per caged truss.
2. 10 adult female *M. caliginosus* from the leaf miner culture per caged truss.
3. Caged truss with no *M. caliginosus.*
4. Uncaged truss.

After three weeks, the cages were removed and the numbers of flowers/fruit, which had dropped prematurely, were recorded.

Results and discussion

Table 7 shows the mean percentage of flowers/fruits that dropped off the trusses in each treatment during the experiment. The presence of *M. caliginosus* resulted in a significant increase in premature flower/fruit drop ($p<0.05$). *M. caliginosus* which had been reared on leaf miners caused more damage than those reared on moth eggs ($p<0.05$) .

Table 7: Mean percentages of flowers/fruits that dropped from trusses prematurely following confinement with *M. caliginosus.*

Treatments	Percentage of flowers/ fruit dropped
1. *M. caliginosus* from the culture based on moth eggs	10.4%
2. *M. caliginosus* from the culture based on leaf miners	29.7%
3. Caged trusses without insects	1.4%
4. Uncaged trusses without insects	1.1%

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2.3. *M. caliginosus* damage to swelling fruit

Materials and Methods

Trusses, with swelling fruits, on growing tomato plants (cv Criterium) were enclosed in fine mesh cages. A single adult female *M. caliginosus* was released in each cage where it was confined for three weeks. The cages were then removed and the fruits examined for symptoms of damage.

Results and discussion

Scars, consisting of a series of small punctures arranged in a typically curved pattern, were observed on two or three fruit on each truss.

2.4. The effect of prey availability on *M. caliginosus* damage to tomato plants

Materials and Methods

Very large numbers of *M. caliginosus* were present in two adjacent cherry tomato crops (cv Favorita) that were seriously damaged by leaf miners. In one crop, *M. caliginosus* had almost completely controlled the leaf miner population and there was very little invertebrate prey remaining. In the other crop, leaf miner larvae were still numerous.

Forty plants were carefully examined in each crop. The numbers of *M. caliginosus* were recorded and their position on the plants noted. The numbers of trusses with one or more fruits lost due to premature drop were also recorded.

Results and discussion

The percentage of trusses with one or more lost fruit, and the mean numbers of *M. caliginosus* per plant are shown in Table 8.

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The numbers of *M. caliginosus* per plant were similar in each crop. In both cases, approximately two thirds of the predators were found in the middle stratum of the plants and the remainder were distributed evenly between the upper and lower strata. This is broadly consistent with the records from the survey of commercial crops (page 17).

The crop damage was most severe where there were least invertebrate prey. This indicates that *M. caliginosus* feed more voraciously on plants after the supply of invertebrate prey has been exhausted.

Table 8: Numbers of *M. caliginosus*, with numerous or few leaf miner prey, compared to premature flower/fruit drop.

Cherry tomato crop (cv Favorita)	Mean no of *M. caliginosus* per/ plant	Leaf miner Numbers	Percentage of trusses with:	
			One fruit lost	More than 1 fruit lost
1	330	Few	81%	52%
2	291	Numerous	31%	14%

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PART 3 - *M. CALIGINOSUS* OVER WINTERING STUDIES

3.1. *M. caliginosus* survival outside glasshouses

Methods

Vegetation outside glasshouses at English Village Salads (Yorkshire) and Bridgeguild Ltd (Isle of Wight) was surveyed in mid-December 1997 and mid-February 1998. A further assessment is scheduled in April 1998, or as soon as the ambient temperatures allow *M. caliginosus* to become active.

In December, many different species of weeds, within 5 m, 5-10 m, and 10-20 m of the glasshouses were examined for *M. caliginosus*. Beating trays were used to collect other insects upon which the predators could have fed. Host plants were identified, taken back to the laboratory and incubated at 21°C for 40 days to determine whether they contained *M. caliginosus* eggs. *Macrolophus* spp collected were identified to species by Dr. D. Collins, Central Science Laboratory, York.

In February, a similar survey concentrated on the plants that had been shown to be *M. caliginosus* hosts in December.

Results and discussion

In December, *Macrolophus* species were found on weeds up to 20 m from the edge of glasshouses. The predators were only found on nettles and thistles although glasshouse managers reported seeing them on deadly nightshade during the summer. All specimens were identified as *M. caliginosus*. The individuals collected in Yorkshire were all adult females, and they were mainly found on nettles within 5 m of the glass. On the Isle of Wight, the population was a mixture of adults and nymphs and they were concentrated on thistles around a compost area, 10-15 m from the glass.

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There was an abundance of invertebrate prey, particularly aphids, at both sites.

No *M. caliginosus* were found in the February survey.

No *M. caliginosus* hatched from the host plants that were collected during the surveys.

3.2. *M. caliginosus* survival between crops inside glasshouses

Methods

Glasshouse block managers at eight nurseries were asked to look for *M. caliginosus* as part of their weekly crop monitoring routine, and to count the numbers of *M. caliginosus* found on 60 plants each week. A monitoring form was supplied to standardise the records (Appendix 2).

Results and Discussion

Live *M. caliginosus* adults were observed in flight and on the floor of empty glasshouses between crops at two nurseries. The predators were also observed in new crops at four of the eight monitored nurseries before any had been released in 1998; up to mid-March small numbers (less than one per 100 plants) had been seen by crop workers on plants while others had been found on yellow sticky traps. Towards the end of March, *M. caliginosus* nymphs were observed feeding on spider mites and leaf miners.

No survival of *M. caliginosus* was recorded at three sites where spray treatments were applied in the empty blocks.

There was no clear difference in survival of *M. caliginosus* between sites in the north or south of the country.

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GENERAL DISCUSSION AND CONCLUSIONS

When it was first suspected that *M.caliginosus* was causing direct damage to tomato plants (Hayman and Jacobson, 1996) there was a mixed response among growers and representatives of the biocontrol supply companies. Many people strongly contested that *M.caliginosus* could cause such damage. The debate has progressed significantly during the intervening year and it is now generally accepted that the predators are capable of damaging tomato crops. The results of studies reported in this document have made a considerable contribution to the improved understanding of the survival of *M.caliginosus* between crops, the factors that influence *M.caliginosus* population growth, the various types of plant damage and the conditions under which that damage occurs. As this information has become available, it has been conveyed to the industry through grower meetings, conferences and an article in HDC News (Jacobson and Sampson, 1998).

It has been shown that *M.caliginosus* can survive routine cleaning procedures in empty glasshouses and colonise the new crop as soon as it is planted. This survival can be significantly reduced by the application of insecticides in empty glasshouses but such treatments are unlikely to eradicate *M.caliginosus* from nurseries because the predators can also survive outside on weeds. It seems probable that tomato growers will have to learn to live with the presence of these insects in their crops.

The *M. caliginosus* populations followed a common growth pattern at most nurseries; building up slowly at the beginning of the season, peaking in July and August, then declining from September. The size of the population peak was influenced by the time and rate of *M. caliginosus* release but was most dependent on the type of tomato and the availability of invertebrate prey. Numbers were greatest in cherry tomato crops, particularly following an infestation of leaf miners or whiteflies, and smallest in cherry plum tomato crops.

A variety of damage symptoms have been recorded in commercial crops and most have been reproduced in small scale experiments. The most important damage is considered to be

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premature flower/fruit drop, which results from *M. caliginosus* feeding on pedicels, flowers or very young fruit. This was observed in all the monitored cherry tomato crops, 30% of the round tomato crops but not in the cherry plum tomato crop.

The earliest damage was recorded in June but it was most commonly seen during August. The timing was strongly influenced by the availability of invertebrate prey. Although *M. caliginosus* can survive on plant material, they live longer and lay more eggs when they feed on invertebrates and numbers increase most rapidly when there are pests in the crop. The difficulties for growers arise after the pests have been controlled and the remaining *M. caliginosus* must feed on plants. Following pest decline, the predator population continues to grow as eggs hatch and the damage usually reaches a peak after a further four to six weeks when those offspring reach maturity.

All the monitored crops that suffered damage had over fifty *M. caliginosus* per plant but this should not be considered to be a definitive threshold because there are several factors that influence damage and the threshold will probably vary depending on the precise combination that occur at any time.

Where damage became unacceptable, growers were able to reduce the predator population and prevent further damage with one or two applications of heptenophos (Hostaquick). However, these treatments often had an adverse effect on other components of the integrated pest management (IPM) programme and biological pollination by bumble bees.

Specific action points

- Growers are advised against introducing *M. caliginosus* in cherry tomato crops as there is a strong probability that crop damage will occur.

- To reduce the risk of *M. caliginosus* surviving between crops, control measures should include both spray treatments in the empty glasshouse and eradication of weeds (particularly nettles and thistles) in the immediate vicinity of the glasshouse.

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- *M. caliginosus* can cause economic damage to round tomato crops but little has been observed where there have been less than thirty *M. caliginosus* per plant or where there has been ample invertebrate prey. To predict the actual risk, growers should assess both the numbers of predators and the availability of prey.

- Although *M. caliginosus* populations grow primarily in response to the availability of invertebrate pest prey, the risk of damage to crops can probably be reduced by delaying release of the predators until April and by releasing less than 0.25 per m^2.

- If *M. caliginosus* survive between crops, there is an increased risk of plant damage because growers have no control over the size of the initial population. It is therefore sensible to wait to see whether the predators become established naturally before releasing more.

Recommendation for further research and development work

Some tomato growers believe that *M. caliginosus* has now become a serious pest and will maintain this status because it can survive between crops. They believe that the highest priority must be to identify an effective control measure that is compatible with all the other components in the tomato IPM programme.

Other growers believe that *M. caliginosus* can make an important contribution to the IPM programme in UK tomato crops if the injury to plants and subsequent financial loss can be avoided. These growers favour a research programme that will improve our understanding of *M. caliginosus* behaviour on all types of tomato and allow populations to be manipulated to obtain the benefits of effective pest control without the harmful effects to the plants.

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The following research programme is being considered by the representatives of the Tomato Growers Association:

1998/99

1. Identification and evaluation of IPM compatible control measures, eg pymetrozine and entomopathogenic fungi.

2. Small-scale studies to determine the relative performance/damage of *M. caliginosus* on specific cultivars of cherry, cherry plum, beefsteak and standard round tomatoes in the absence of pests.

1999/00

1. Small scale studies to determine how variables such as environmental conditions, prey type, prey availability and plant condition influence *M. caliginosus* performance/damage on the same range of tomatoes.

2. Formulation of a strategy to maximise benefits of *M. caliginosus* whilst minimising plant damage.

2000/01

Crop scale evaluation of a strategy to maximise benefits of *M. caliginosus* while minimising plant damage.

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APPENDIX 1:

MACROLOPHUS: MONITORING IN TOMATO CROPS

Assessor:	**Date:** / /97
Site:	**Block Reference:** (If only part affected provide plan overleaf)

MACROLOPHUS

Number Introduced: /m²	**Approx. Number per Plant NOW:**
Date of Introduction: / /97	Adults ....
/ /97	Nymphs ....

POSITION ON PLANT (✓ or X)			
Lower stratum		On Leaves	
Middle stratum		On Flowers	
Upper stratum		On Fruit	

PREY

	0	F	M	L	Notes (eg changes in populations/position on plant)
Whitefly					
Spider Mites					
Leaf Hopper					
Leaf Miner					
Other (specify)					

F = Few, M = Moderate, L = Large Numbers

PLANT

Cultivar	**Anything Abnormal:**
Planting Date / /97	
Final Head Density: /hectare	

APPENDIX 2:

MACROLOPHUS OVERWINTERING MONITORING

Assessor:	**Date:**
Site:	**Block:**

MACROLOPHUS

COMMENTS:

Number per plant	Tick Box
None	
< 1 per 100 plants	
1/100 to 1 per 10 plants	
1/10 to 1 per plant	
> 1 per plant (estimate no/plant)	

PREY

Pest Type	None	Few	Mod.	Many
Whitefly				
Spider Mites				
Leaf Hopper				
Leaf Miner				
Other (Specify)				

CROP DETAILS AND CLEAN-UP PROGRAMME

Cultivar:	
Date plants put out:	
Date previous crop removed	
No of days between crops:	

Clean-up sprays	Treatment Type	No of applications
Before pulling out		
In the empty block		
Other		

Please return to: Clare Sampson, HRI Stockbridge House, Cawood, North Yorkshire, YO80TZ