Project title:	Celery: Investigation of strategies to control mirid bugs in outdoor crops
Project number:	FV 441
Project leader:	Rosemary Collier, University of Warwick
Report:	Final report March, 2017
Previous report:	None
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Location of project:	G's, Warwick Crop Centre, Stockbridge Technology Centre
Industry Representative:	Emma Garfield, G's
Date project commenced:	1 April 2015
Date project completed (or expected completion date):	31 March 2017

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The results and conclusions in this report are based on an investigation conducted over a two-year period. The conditions under which the experiments were carried out and the results have been reported in detail and with 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 interpretation of the results, especially if they are used as the basis for commercial product recommendations.

AUTHENTICATION

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

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CONTENTS

GROWER SUMMARY

Headlines

- Species of *Orthops,* particularly *Orthops campestris* have been confirmed as the pest mirids causing most damage to celery crops in eastern England. *Orthops campestris* appears to feed mainly, or possibly entirely, on wild and cultivated members of the carrot family (Apiaceae).
- Laboratory trials identified a small number of insecticides that were partially effective against adults of this species and a number of potential predators including species occurring naturally in the field.

Background

Recent high incidences of mirid damage in celery suggest that the status of mirids as pests of this crop is increasing, particularly in organic crops. Crop invasion by mirids is unpredictable and relatively little is known about their biology, which would inform the development of an integrated control strategy for celery. Current control of mirids in celery relies on the use of a small number of generally broad-spectrum synthetic insecticides. Options for control of mirids in organic crops are very limited. The aim of this project is to improve current understanding of the complex of mirid bugs that can infest celery crops, identify the key pest species and identify and evaluate approaches to control.

Summary

Objective 1 Develop a clearer understanding of the identity and life cycles of the key species of mirid bug which infest celery crops in the UK.

Crop sampling was carried out regularly in 2015 and 2016 in organic and conventional celery crops. Five plants per week from an uncovered area were carefully pulled up and shaken into an insect-proof bag and mirids were saved for identification. Sampling of field margins was also carried out. At each site four lengths of 5 m along the margin were marked out and one section was swept each week using five sweeps of the net. Further samples were collected from field margins surrounding organic crops by Ela Witkowska from G's since April 2014. The most abundant species of mirid was identified as *Orthops campestris* (Figure A) and this identification was verified by Joseph Botting an expert on plant feeding bugs (British Bugs http://www.britishbugs.org.uk/). There are other species of *Orthops* in the UK (*Orthops kalmii*, *Orthops basalis*) and a specimen of *O. kalmii* was also identified in a crop sample. Only *Orthops* spp. adults were found in the crop samples.

Figure A. Adult *Orthops campestris* and celery plant damaged by mirid bugs

Damage in 2015 was seen particularly in crops of organic celery between early July and the end of August (Figure A). There was no damage in conventional crops in 2016 and the organic crops were covered with fine mesh netting. Adult *Orthops* spp., common green capsid (*Lygus pabulinus*) and European tarnished plant bug (*Lygus rugulipennis*) were found in samples from the field margins. A large proportion of the mirids from the samples from the field margins were nymphs. Figure B compares the abundance of adults and nymphs in samples from field margins around organic crops in 2014, 2015 and 2016. The data suggest that there were three ‘peaks’ in the numbers of nymphs each year.

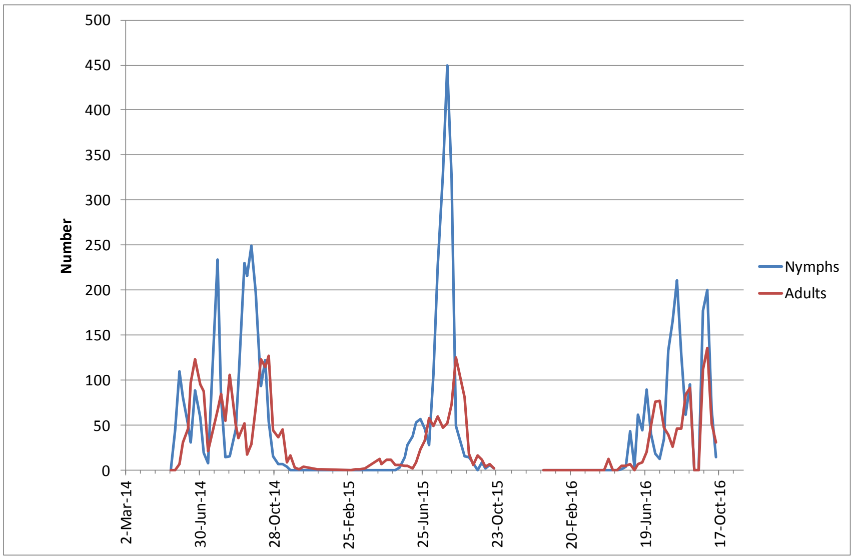

Figure B. Numbers of adults (*Orthops* spp.) and nymphs (identification not verified) sampled from the vegetation surrounding organic crops of celery at G’s Cambs in 2014-2016 (data provided by E. Witkowska).

The timing of peaks in the numbers of nymphs in 2014-2016 were compared both in calendar time and using day-degrees. Accumulated day-degrees above thresholds of 8 or 10°C were estimated using weather data from G’s. The day-degree sums from 1 January to peak numbers of first and second generation nymphs appear remarkably consistent, although the day-degree sum to the third generation is more variable; which might be related to the influence of day-length on the occurrence of adult diapause. This provides a preliminary forecasting system for this pest that requires further field validation. More detailed sampling of potential hosts was undertaken in 2016. The bugs were abundant on wild carrot (*Daucus carota*) and hemlock (*Conium maculatum*) in particular. They appeared to aggregate in the vicinity of apiaceous crops apart from celery and were captured on carrot fly traps in carrot plots at Wellesbourne. To investigate the association with Apiaceae in more detail, carrot fly traps were placed in locations with and without apiaceous hosts – crops and weeds. No *Orthops* spp. were captured in locations where Apiaceae were absent and the largest numbers were captured close to plots of carrot. This suggests that proximity to, and management of, apiaceous weeds will be a key factor.

Objective 2 Once the key species have been identified, determine the feasibility of rearing them in the laboratory or under semi-field conditions, so that more detailed studies can be undertaken on their life-cycle and on methods of control.

Large numbers of mirids were collected at G's in August 2015. The mirids were placed in cages in a controlled environment room at 15°C. Potential food plants were provided. Initially there were a large number of nymphs in the samples, but these appeared to die quite rapidly. The adult population remained relatively constant until late December but after this it declined. The behaviour of the caged adult *Orthops* spp. was observed. At any moment a proportion of the adults were on the ceiling of the cage, suggesting that they were displaying dispersal behaviour; adults were most numerous on the cage ceilings in the middle of the day. Further insects were collected in 2016 and kept in cages in rooms at 15, 18 and 20ºC. Numbers were monitored and in all cases there was evidence of a resurgence in numbers in December, followed by decline in numbers from mid-December onwards.

Objective 3 Using the information from Objective 1, review possible strategies (including the use of insecticides or crop covers) for managing populations of mirid bugs in the vicinity of celery crops.

Approaches used to manage *Orthops* spp. and other pest mirids were reviewed. They included pheromones for monitoring, insecticidal and biological control, management of vegetation (e.g. field margins) and physical removal of bugs with vacuum equipment.

Objective 4 Evaluate products approved currently for application to celery and novel insecticides and bio-insecticides that might be used to control mirid bugs in small-scale field trials and undertake a small scale study of potential biocontrol agents (predators).

A replicated laboratory trial was undertaken to compare foliar spray treatments (9 treatments and untreated control) applied to caged potted celery plants that were infested post-treatment with mirids (*Orthops* spp.) collected from wild carrot. Test plants were taken outside and the treatments were applied using a knapsack sprayer. The plants were then placed in cages (one plant per cage) and ten adults were added to each cage. The cages were kept at 20ºC and the numbers of live mirids were assessed 1, 2, 3 and 6 days after spraying (Figure C). Analyses of data collected on Day 2, Day 3 and Day 6 showed that there was a statistically significant effect of insecticide treatment on the percentage live adults on each occasion. The percentage live adults declined over time but none of the treatments reduced numbers rapidly. Two days after spraying only lambda-cyhalothrin had reduced the percentage live adults compared with the untreated control. Three days after spraying HDCI 098, HDCI 105 and HDCI 107 had also reduced the percentage live adults and this pattern was repeated 6 days after spraying. There was little difference between the effective treatments, but 6 days after spraying HDCI 098 had reduced the percentage live adults significantly compared with HDCI 105.

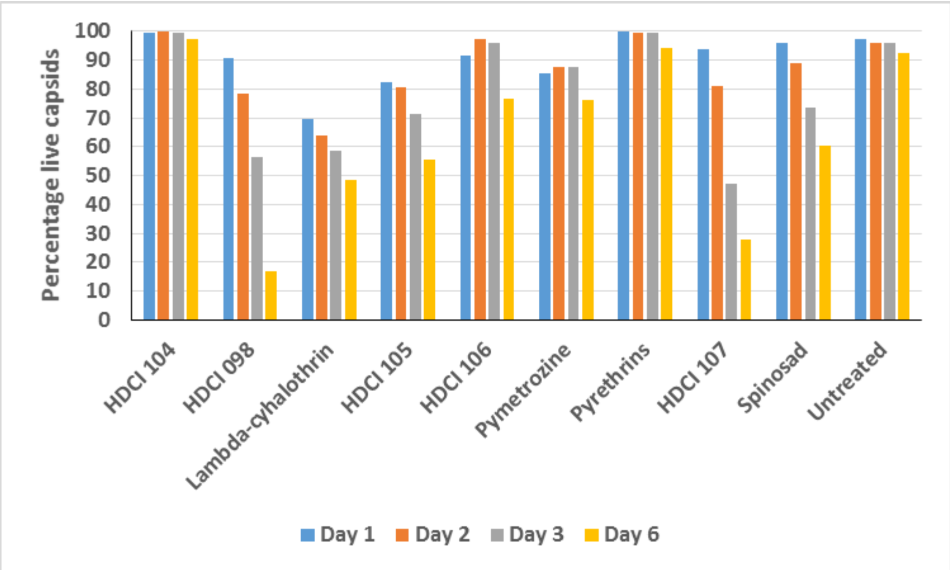

Figure C. The mean percentage live mirids (adults) 1, 2, 3 and 6 days after spraying.

A laboratory screening study was conducted at Stockbridge Technology Centre to assess the impact of various predatory natural enemies on the mortality of *Orthops* spp. Two types of natural enemies were considered: 'commercially-available' and 'wild-caught'. Screening was conducted on juvenile and adult *Orthops* spp., sourced from wild hosts near the Wellesbourne

Campus. Three sets of experiments were conducted within Petri dishes in a controlled temperature room. A pre-determined number of adult and juvenile mirids were placed within each dish with a section of organically grown celery and a small piece of cotton wool soaked in 50% honey solution. Natural enemies and commercially-available biocontrols were then introduced and mortality of the mirids and natural enemies was measured 4 days after predator introduction. The naturally-occurring predators selected in an initial screening consisted of web-forming spiders, ladybirds, soldier beetles, earwigs, sawflies, pirate bugs, damsel bugs, harvestmen and lacewing larvae. The mortality of mirids in 'control' treatments (in the absence of natural enemies) was less than 10%. Initial screening indicated higher mortality of mirids in dishes containing web-forming spiders, earwigs, damsel bug spp. and harvestmen, and to a lesser extent ladybirds, soldier beetles and lacewing larvae. Encouragingly, the most effective natural enemies all appeared to feed on adult mirids as well as juveniles. Nevertheless, as juvenile mirids were at a relatively late stage when used, and matured during the course of the study period in some dishes, it was not possible to reliably separate out which stage had been attacked. Based on these results, certain wild-caught natural enemies were selected for further, replicated screening on adult mirids. Spiders and field damsels both appeared to reduce numbers of adults. However, the data were highly variable. Earwigs and harvestmen did not cause a significant level of mortality in this experiment. When commercially available predators were screened (*Macrolophus pygmaeus* (Mirical-N), *Orius strigicollis* (Thripor-S) and *Atheta coriaria* (Staphybug)), juvenile mirids were available at a younger stage than previously. In general, juveniles were preferred to adults by all natural enemies tested, particularly by *Orius* and *Atheta* and less so by *Macrolophus*. The potential of certain natural enemies, whilst suggested by these results, can only be confirmed with further study under field conditions. There is potential to consider the efficacy of egg parasitoids in future.

Objective 5 Determine the potential and significance of improved monitoring and forecasting of infestations by mirid populations.

The most effective method of monitoring *Orthops* spp. in field margins appears to be through tapping/shaking foliage above a large plastic tray and rapidly recovering/counting insects that land on the tray. Celery crops provide an additional challenge in terms of sampling, which almost inevitably must be destructive and involves either shaking an uprooted plant into a bag or taking the plant apart as quickly as possible *in situ*. The use of orange sticky traps may be a promising approach for monitoring activity when populations are high. Whether such traps could be used to determine the risk of damage to crops would require further research. Any approach to indicate the timing of activity could be useful in terms of targeting treatments. The later generations appear to be more abundant and potentially more damaging and an indication of their timing may be useful.

Objective 6 Identify promising approaches that could be investigated in a subsequent project.

This study and G's own observations and activities have indicated two potential approaches to management, the first is the use of crop covers made of fine mesh netting to exclude all stages of *Orthops* spp. G's have demonstrated that this approach successfully excludes the bugs, although it may have other consequences. For example, the presence of the covers may exacerbate infection by pathogens and reduce crop quality. The use of crop covers also presents challenges for effective weed control, is expensive and labour intensive. However, this approach is particularly important for organic crops where there are currently no effective control options; the trial addressing Objective 2 confirmed that pyrethins are ineffective against adult *Orthops* spp. This study has confirmed the significance of wild Apiaceae in sustaining populations of *Orthops spp.* and the strong association between their presence and the presence of the pests. This indicates that management of vegetation in field margins may be one of the most effective ways of reducing the abundance of this pest. It would be interesting to investigate whether sticky traps could be used to indicate the 'risk' of damaging infestations occurring. Although it has not been possible to rear *Orthops* spp. on a continuous basis and the reasons for this require further research, it does appear feasible to collect adults in large numbers and maintain them over reasonable periods to evaluate control methods in a laboratory setting. Thus it should be feasible to screen other potential control agents as they arise and it may be possible to do this within SCEPTREplus. It would be good to determine a method of producing nymphs or sustaining field-collected nymphs over longer periods so that these could also be tested. Similarly, a reliable method of egg production would be required to evaluate egg parasitoids.

Financial Benefits

Mirid damage has been particularly devastating in organic celery crops with potential annual losses of £2 million. The project has identified the key pest species, provided further information about their biology, and identified ways of improving mirid control. The results are most applicable to celery producers. The findings may also have relevance for the control of additional pests of celery and other crops sharing a similar life-cycle/biology.

Action Points

- Growers should monitor crops and margins using sweep nets/trays to determine levels of *Orthops* spp. activity, which will be useful in helping to time control methods.

SCIENCE SECTION

Introduction

Mirid bugs damage fruit and protected crops in the UK and are also pests of certain species of ornamental plant. Though considered sporadic pests of vegetable and salad crops grown outdoors, recent high incidences of mirid damage in celery suggest that the status of mirids as pests of this crop is increasing, particularly in organic crops. Crop invasion by mirids is unpredictable and relatively little is known about their biology, which would inform the development of an integrated control strategy for celery, although if the main pest species are common green capsid and European tarnished plant bug then information and techniques developed for strawberry crops might be used.

Current control of mirids in celery relies on the use of a small number of generally broad-spectrum synthetic insecticides. In organic crops, control is now reliant on the use of mesh covers, which work well if applied at the right time and well-sealed. The aim of this project is to improve current understanding of the complex of mirid bugs that can infest celery crops, identify the key pest species and identify and evaluate approaches to control.

Mirid bugs damage fruit and vegetable crops in the UK and are also pests of certain species of ornamental plant. Several species of mirid bug appear on top fruit and soft fruit. The common green capsid (*Lygus pabulinus*) has been damaging to apples, pears and blackcurrants for many years, where it feeds on young leaves in shoot tips, puncturing the plant tissue and sucking sap, causing twisting of leaves and stunting of new growth. In the past 15-20 years, common green capsid populations have been increasingly found in strawberry and cane fruit crops. The European tarnished plant bug (*Lygus rugulipennis*) is a newer pest in the UK and was first found damaging strawberry crops in the early 1990s. It can cause similar damage to common green capsid, affecting shoot tips, but is also known to forage on developing flowers, leading to serious fruit malformation and fruit wastage. European tarnished plant bug is also a pest of glasshouse salad crops including cucumbers and peppers, where it causes foliage twisting and stunting. In 1996, the AHDB commissioned a project (PC123 - Control of mirid bugs within IPM programmes in protected crops) aimed at improving the knowledge of the behaviour of plant feeding mirids in protected salads, as a first step in formulating a sustainable control strategy within the existing IPM programmes. Detailed crop monitoring at several sites in Yorkshire showed that two species were causing damage: *Lygus rugulipennis* in cucumber crops and *Liocoris tripustulatus* in pepper and aubergine crops.

Over time, the AHDB have funded several other projects on the management of mirids but these have focused mainly on strawberry. The most recent research has been through:

1. A Horticulture LINK project (HL 0184, PC/SF 276) started in 2007. The project set out to identify the sex pheromones of both mirid species (common green capsid and European tarnished plant bug) with the aim of developing improved methods of monitoring the pests. The end result was the production of two types of pheromone trap which incorporate lures for the common green capsid and the European tarnished plant bug respectively. By using these traps, growers can monitor for the arrival of the two mirids, allowing them to time the application of any chemical control. Work in the project also developed pest thresholds for each trap, which act as a trigger for the use of control measures.
2. A day-degree forecast for European tarnished plant bug was developed in a subsequent AHDB project (SF 114 Development of temperature degree-based models to predict pest development on strawberry for optimisation of control strategies).
3. In another Horticulture LINK project, the SCEPTRE project, novel insecticides and bio-insecticides for control of European tarnished plant bug were evaluated at East Malling Research.

Though considered a sporadic pest of vegetable and salad crops grown outdoors, recent high incidences of mirid damage in celery (Figure 1) suggest that the status of mirids as pests of this crop is increasing, particularly in organic crops (David Norman, personal communication). Three species of mirid have been seen in the vicinity of infested celery crops: common green capsid, European tarnished plant bug and what appears to be *Orthops campestris,* which does not have a common name. Observations by Elzbieta Witkowska and Rosemary Collier suggested that *O. campestris* may be the cause of most of the damage. Crop invasion by mirids is unpredictable and relatively little is known about their biology, particularly the biology of *Orthops* spp., which would inform the development of an integrated control strategy for celery. However, if the main pest species are common green capsid and European tarnished plant bug then information and techniques developed for strawberry crops might be used. It is a critical starting point for any project that the species involved are identified and we know which of these species are responsible for what proportion of crop damage.

Figure 1. Celery plant damaged by mirid bugs.

Current control of mirids in celery relies on the use of a small number of generally broad-spectrum synthetic insecticides; primarily Plenum (pymetrozine) and pyrethroids including Hallmark (lambda-cyhalothrin), as well as Tracer (spinosad), but we do not know their relative efficacy. In organic crops, control is reliant on the use of mesh covers, which work well if applied at the right time and well-sealed. However, the presence of the covers may exacerbate infection by pathogens such as celery late blight, *Septoria apiicola,* and reduce crop quality. The use of crop covers also presents challenges for effective weed control, is expensive and labour intensive.

Some information on the biology of the mirids has been obtained at G's over the last couple of years. The pheromone traps developed for the common green capsid and European tarnished plant bug have been used to monitor these species and headlands have been sampled by sweep netting or similar approaches. David Norman has obtained high catches under elder bushes with nettles growing under them and Elzbieta Witkowska and Rosemary Collier have observed adult mirids feeding on the flowers on wild members of the carrot family (Apiaceae).

The aim of this project is to improve current understanding of the complex of mirid bugs that can infest celery crops, identify the key pest species, and identify and evaluate approaches to control.

Project objective(s):

1. Develop a clearer understanding of the identity and life cycles of the key species of mirid bug which infest celery crops in the UK.
2. Once the key species have been identified, determine the feasibility of rearing them in the laboratory or under semi-field conditions, so that more detailed studies can be undertaken on their life-cycle and on methods of control.
3. Using the information from Objective 1, review possible strategies (including the use of insecticides or crop covers) for managing populations of mirid bugs in the vicinity of celery crops.
4. Evaluate products approved currently for application to celery and novel insecticides and bio-insecticides that might be used to control mirid bugs in small-scale field trials and undertake a small scale study of potential biocontrol agents (predators).
5. Determine the potential and significance of improved monitoring and forecasting of infestations by mirid populations.
6. Identify promising approaches that could be investigated in a subsequent project.

Experimental

Objective 1 Develop a clearer understanding of the identity and life cycles of the key species of mirid bug which infest celery crops in the UK.

Materials and methods

Crop sampling

In 2015 crop sampling was carried out regularly in organic celery crops once pest activity started, for around 4-6 weeks per site whilst the crop was at the right growth stage to be attractive to mirids (Table 1.1). Five plants per week from an uncovered area were carefully pulled up and shaken into an insect-proof bag and mirids were collected. The occasional mirid found during conventional crop walking was also captured and saved in pots with alcohol.

Table 1.1. Crop sampling sites in 2015

Field	Farm	Location	OS	Weekly samples
Severals	Dimmock Cotes	Stretham	TL 53437 73143	24 Aug-7 Oct
College Field	Hainey Farm	Barway	TL 54389 76196	24 Aug-7 Oct
Mortlocks	Hainey Farm	Barway	TL 54692 74373	7 Jul –18 Aug
21 & 8	Hainey Farm	Barway	TL 54057 74275	7 Jul –11 Aug

Four conventional celery crops were sampled in 2016 using the same approach (Table 1.2). The organic celery crops at G's were covered with fine mesh netting to exclude mirid bugs and so it was inappropriate to sample them in this way.

Table 1.2. Crop sampling sites in 2016

Field	Farm	Location	OS	Weekly samples
Howes Ground	Dimmock Cotes	Stretham	TL 53245 73000	16 May–6 Jun
Hobbs 10	Hainey	Barway	TL 56436 75966	6 Jun–18 Jul
Popes	Hainey	Barway	TL 53756 74911	25 Jul–24 Aug
Seven Stars	Hainey	Barway	TL 53919 75396	2 Aug–3 Oct

Sampling field margins

In 2015, sampling of field margins was carried out at 4 locations on G's farms where celery was grown from 1 April until 28 September and thereafter at fortnightly intervals until 7 December. An additional location where no celery was grown was also sampled later in the season. Details of these sites are shown in Table 1.3. At each site 4 lengths of 5m along the margin were marked out and one section was swept each week using 5 sweeps of the net. If anything resembling a mirid was caught it was placed in a pot with alcohol and labelled with location and date. Further sites were sampled in this way in 2016 (Table 1.4)

Table 1.3. Sites where field margins were sampled in 2015

Field	**Farm**	**Location**	**OS reference**	**Weekly samples**
Celery fields				
Nightingales	Dimmock Cotes	Stretham	TL 53324 71938	1 Apr-7 Oct
45 Acres	Hainey Farm	Barway	TL 53867 74918	1 Apr-7 Oct
ST51/52	Cole Ambrose	Ely	TL 58089 78461	1 Apr-7 Oct
R42	Rosedene	Southery	TL 68779 93768	1 Apr-7 Oct
Non-celery field				
Tractor HQ	Plantation	Littleport	TL 61240 89091	18-Aug- 7 Oct

Table 1.4. Sites where field margins were sampled in 2016

Field	Farm	Location	OS reference	Weekly samples
M & N Triangle	Pioneer	Southery	TL 66211 94326	3 Feb–19 Apr
45 Acre	Hainey Farm	Barway	TL 53867 74918	3 Feb–17 Oct
Hobbs 10	Hainey	Barway	TL 56436 75966	6 Jun-18 Jul
Horse	Hainey	Barway	TL 54524 73757	3 Feb –17 Oct
Padney 56 acres	Hainey	Barway	TL 54542 73826	3 Feb–17 Oct
R42	Rosedene	Southery	TL 68779 93768	28 Apr-3 Oct
Rose	Plantation	Littleport	TL 61411 87854	3 Feb–17 Oct
ST 13	Cole Ambrose	Ely	TL 58605 78823	3 Feb–17 Oct

Additional samples from field margins

Further samples were collected from field margins surrounding organic crops by Ela Witkowska from G's who used a method of 'tap sampling' (Xu *et al*., 2014). A rigid plastic board was used as a tray. The tray was placed underneath the plants and they were tapped by hand a few times in each place. The method is used by other growers e.g. strawberry growers to monitor the first appearance of mirid bugs (Xu *et al*., 2014). Sampling started in April 2014 and has been effectively continuous since then. All of the samples were from fields where organic crops of celery were grown.

Results

Sampling in crops

The most abundant species of mirid was identified as *Orthops campestris* and this identification was verified by Joseph Botting an expert on plant feeding bugs (British Bugs http://www.britishbugs.org.uk/). There are other species of *Orthops* in the UK (*Orthops kalmii*, *Orthops basalis*) and a specimen of *O. kalmii* was also identified in a crop sample. Although external characters are useful, some specimens cannot be reliably identified without dissection. *Orthops campestris* is usually green or green-tinged and is the smallest and most oval *Orthops* species. Only *Orthops* spp. adults were found in the crop samples in 2015 and 2016 (one individual in 2016).

The key feature used in this project to identify adult *Orthops* spp. was that they are green in colour. It was obviously impractical to identify all samples by dissection and in any case this meant killing the insect so was not appropriate much of the time. There is the possibility that a proportion of individuals were not *O. campestris*.

Figures 1.1 and 1.2 show *Orthops* spp. adults (probably *O. campestris* as green in colour) from and in the field margins at G's in 2015.

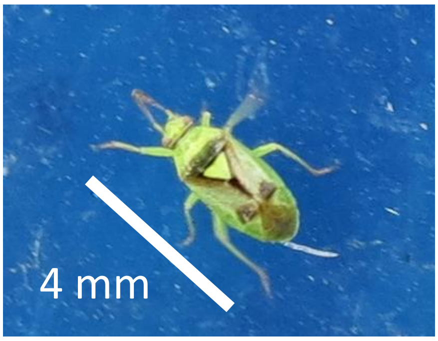

Figure 1.1. Adult *Orthops campestris* on sampling tray.

Figure 1.2. Adult *Orthops campestris* adult on umbel.

Sampling from field margins

Figures 1.3 and 1.4 show the proportions of adult *Orthops* spp., common green capsid (*Lygus pabulinus*), tarnished plant bug (*Lygus rugulipennis*) and unidentified nymphs in samples from the crop and the field margins in 2015. A large proportion of the mirids from the samples from the field margins were nymphs (70%). Some of these at least (from their size) appeared to be nymphs of the common green capsid.

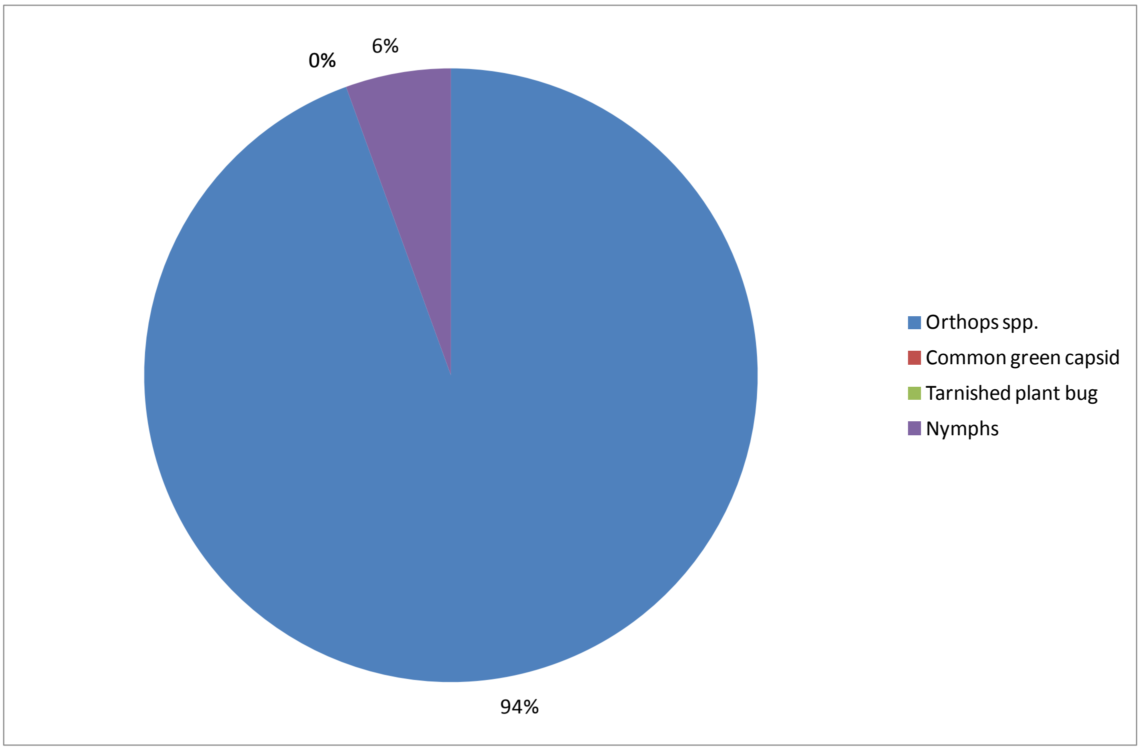

Figure 1.3. Proportions of adult *Orthops* spp., common green capsid (*Lygus pabulinus*), tarnished plant bug (*Lygus rugulipennis*) and unidentified nymphs in samples from the celery crop in 2015.

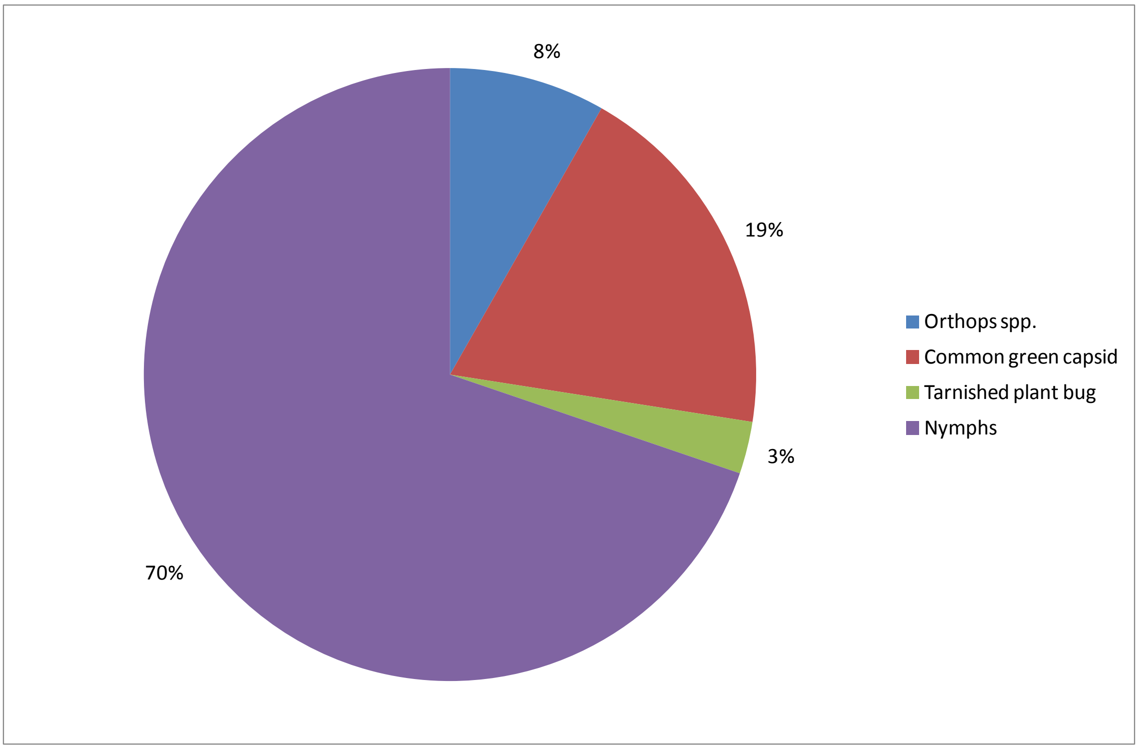

Figure 1.4. Proportions of adult *Orthops* spp., common green capsid (*Lygus pabulinus*), tarnished plant bug (*Lygus rugulipennis*) and unidentified nymphs in samples from the field margins in 2015.

Figures 1.5–1.8 show the numbers of adults of each species captured versus date for the samples from the field margins and the celery crop (*Orthops* spp. only) in 2015. Adult *Orthops* spp. were found from June to September.

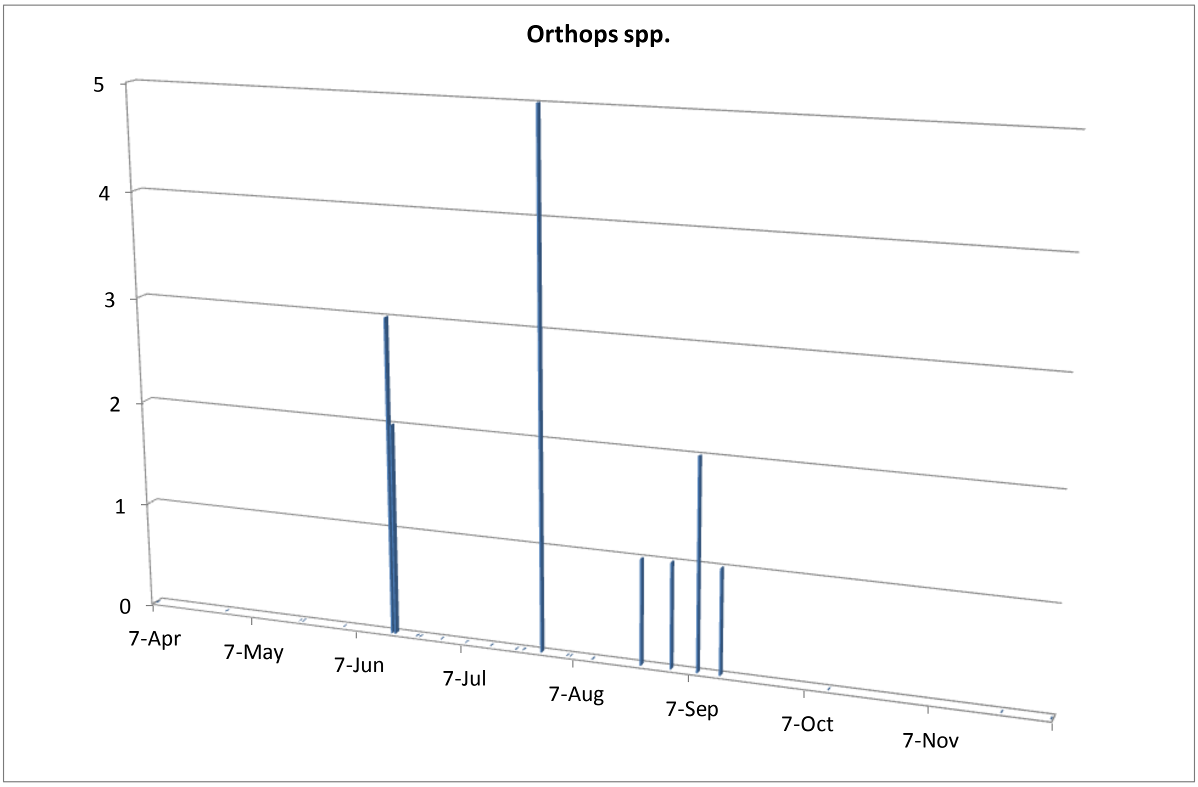

Figure 1.5. Numbers of adult *Orthops* spp. in samples from the field margins in 2015.

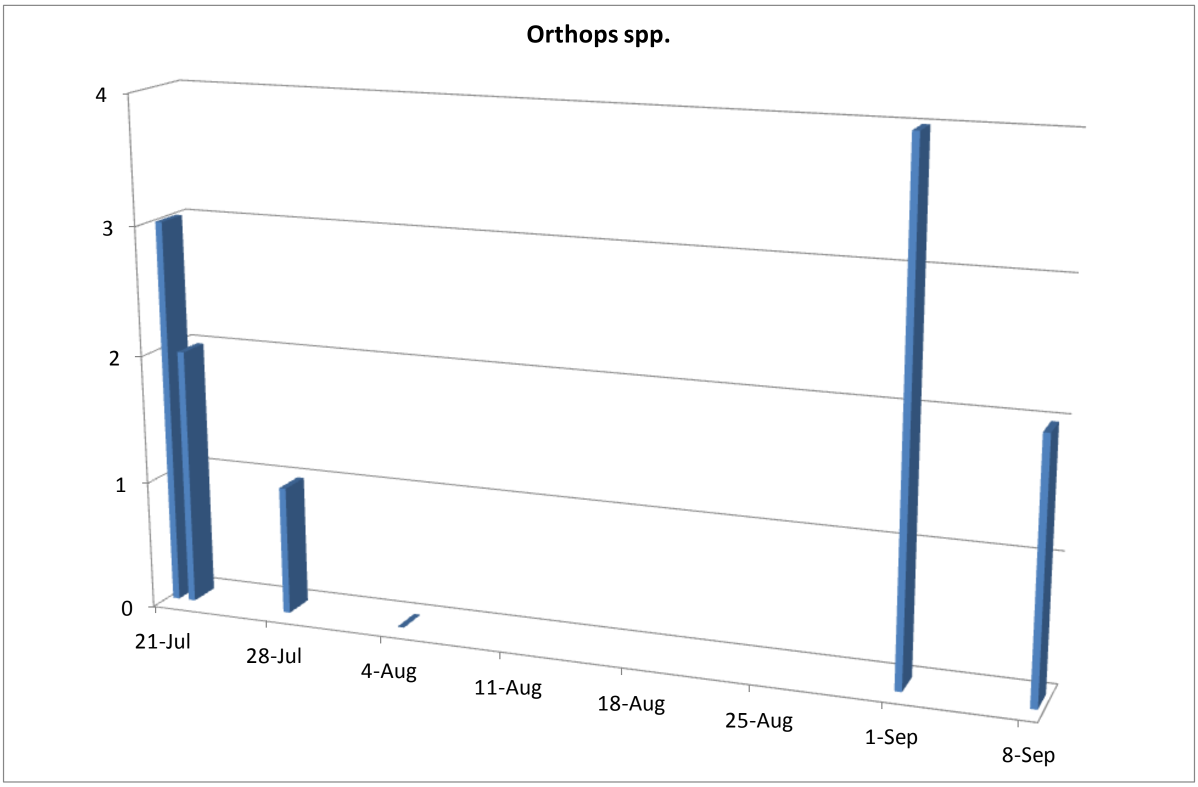

Figure 1.6. Numbers of adult *Orthops* spp*.* in samples from the celery crop in 2015.

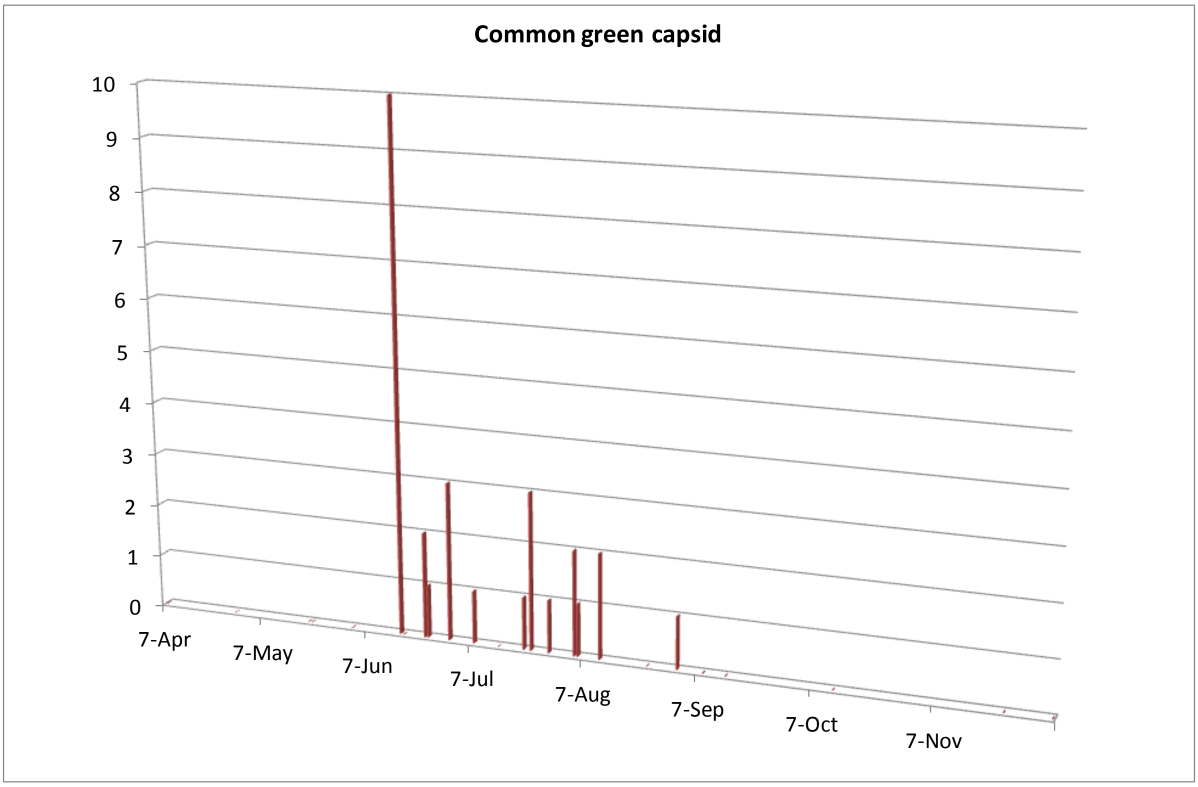

Figure 1.7. Numbers of adult common green capsid in samples from the field margins in 2015.

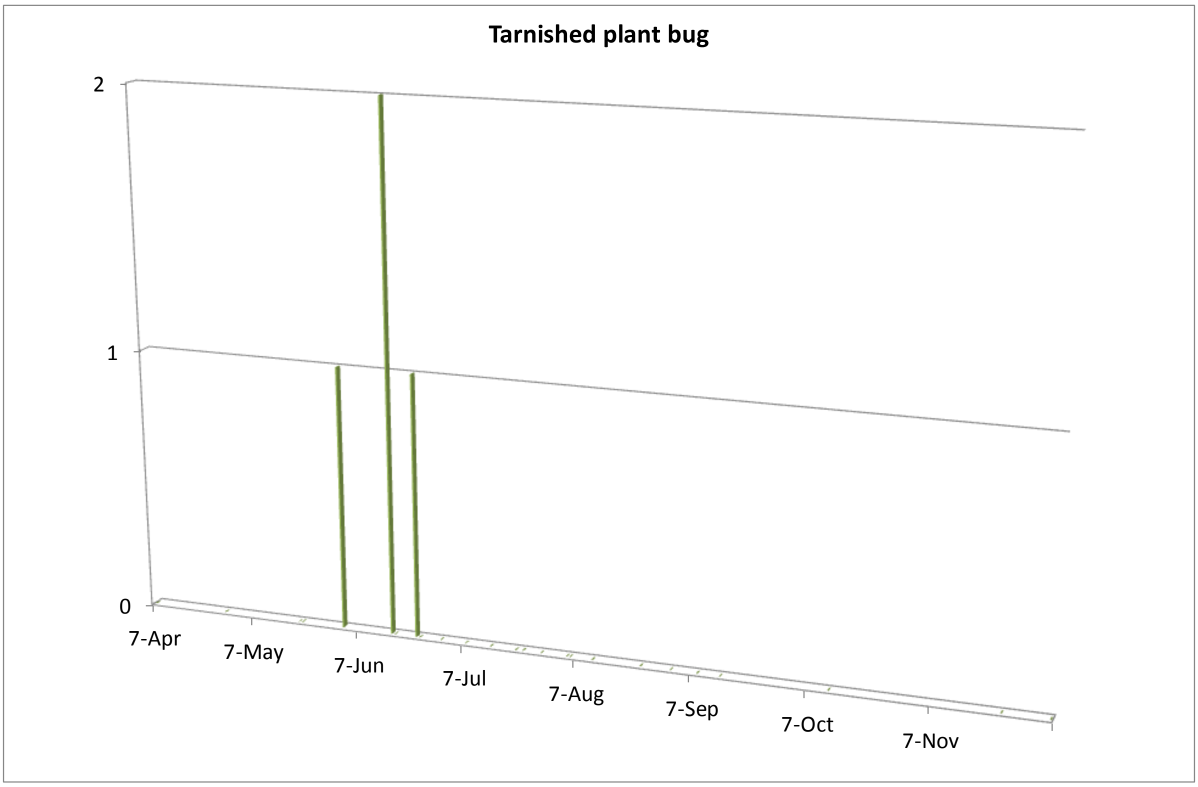

Figure 1.8. Numbers of adult European tarnished plant bug in samples from the field margins in 2015.

2016

The data for field margins close to conventional crops are shown in Figures 1.9 and 1.10. All three species of pest mirid were found.

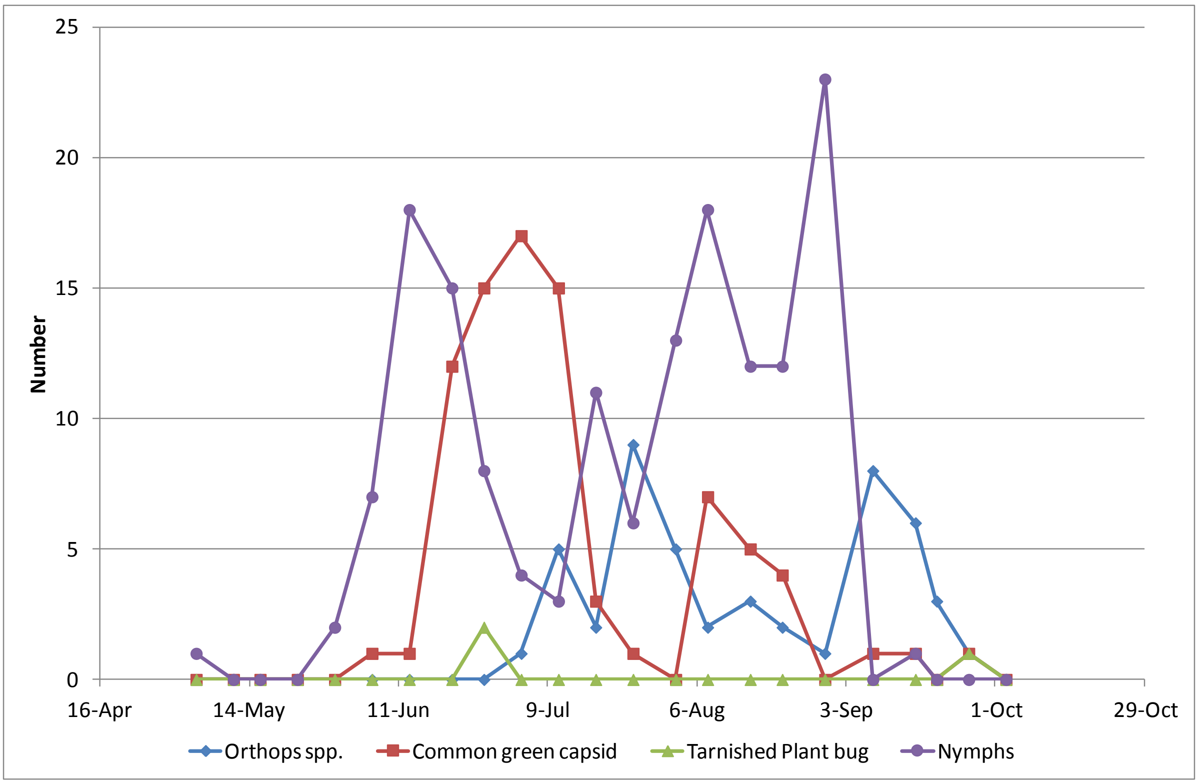

Figure 1.9. Numbers of pest mirids in samples from the field margins surrounding conventional celery crops at G's in 2016.

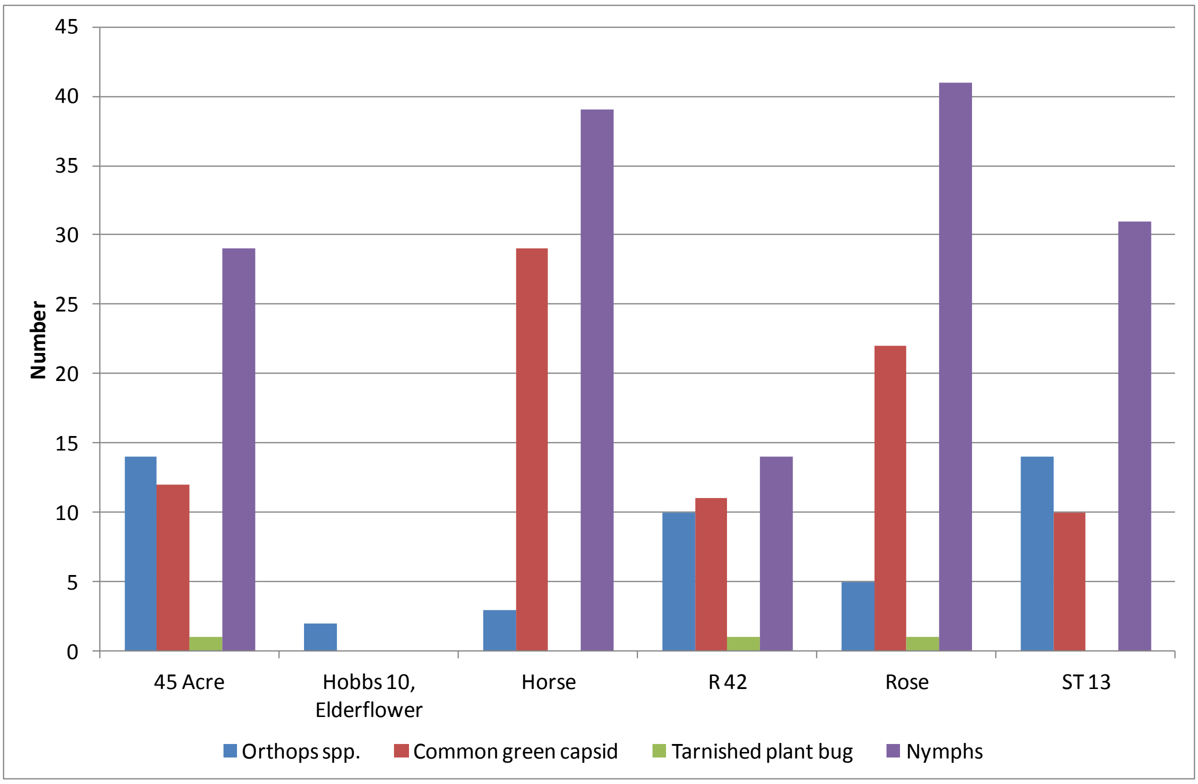

Figure 1.10. Numbers of pest mirids in samples from the field margins surrounding conventional celery crops at G's in 2016.

Additional samples from field margins

Figures 1.11 and 1.12 summarise captures of adults and nymphs in the vegetation surrounding organic crops of celery at G's in taken by Ela Witkowska in 2014. The first samples were taken on 15 May 2014. There are potentially 3 'peaks' in activity for both adults (late June, early August, October) and nymphs (early June, late July, mid-September). The first and third peaks are clearer than the second peak.

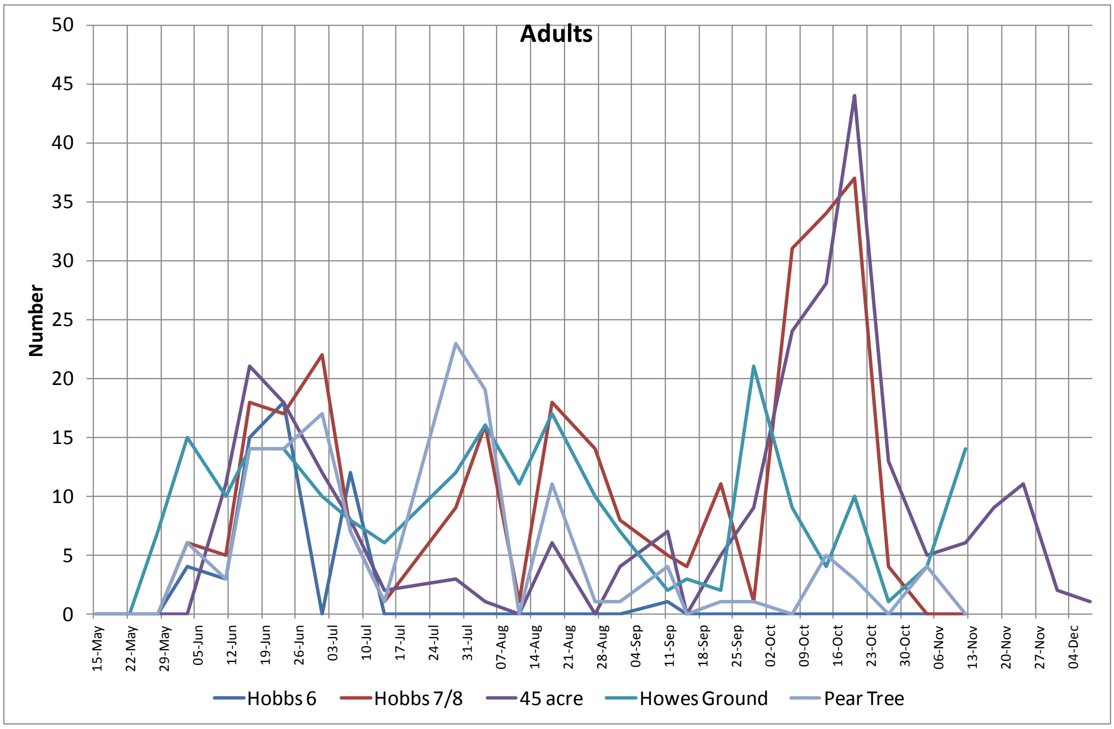

Figure 1.11. Numbers of adults (*Orthops* spp.*)* in samples from the vegetation surrounding organic crops of celery at G's in 2014 (data provided by E. Witkowska).

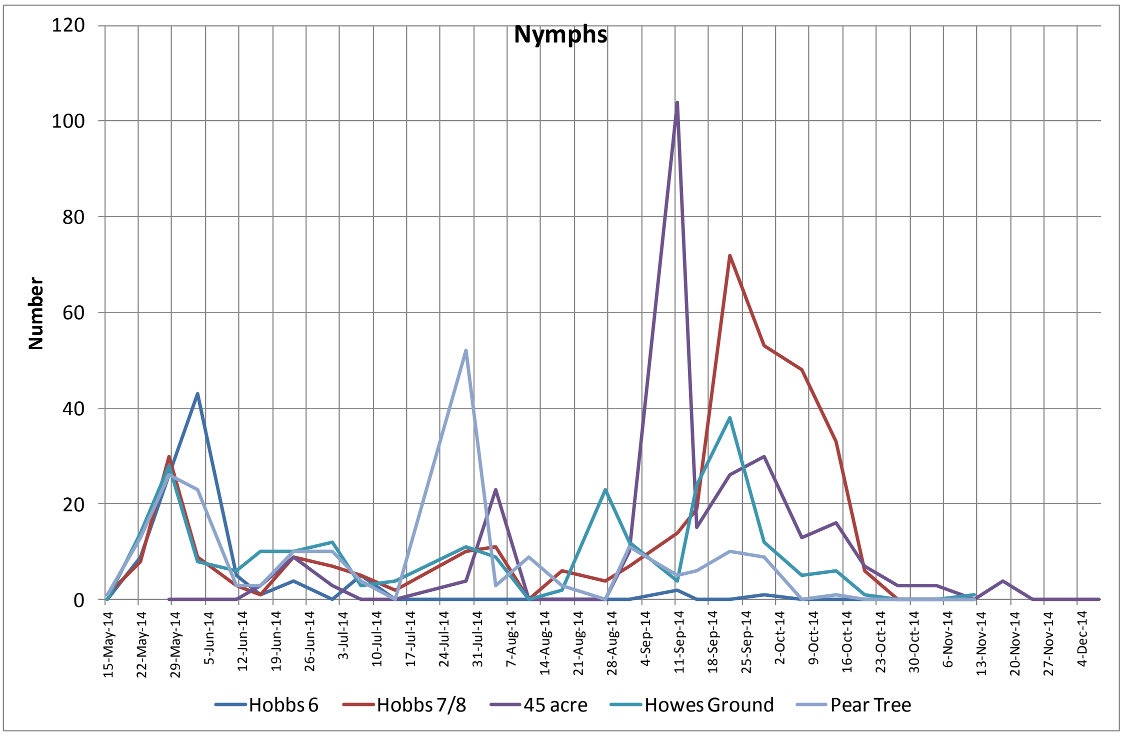

Figure 1.12. Numbers of nymphs (identification not verified) in samples from the vegetation surrounding organic crops of celery at G's in 2014 (data provided by E. Witkowska).

Similar data are shown for 2015 in Figures 1.13 and 1.14. A small number of adults were found in January – March, larger numbers were found from mid-April until early May. The largest numbers of adults were found in July and August. Nymphs were first found on 19 May and then were present until early October, the largest numbers being found between late-July and mid-August.

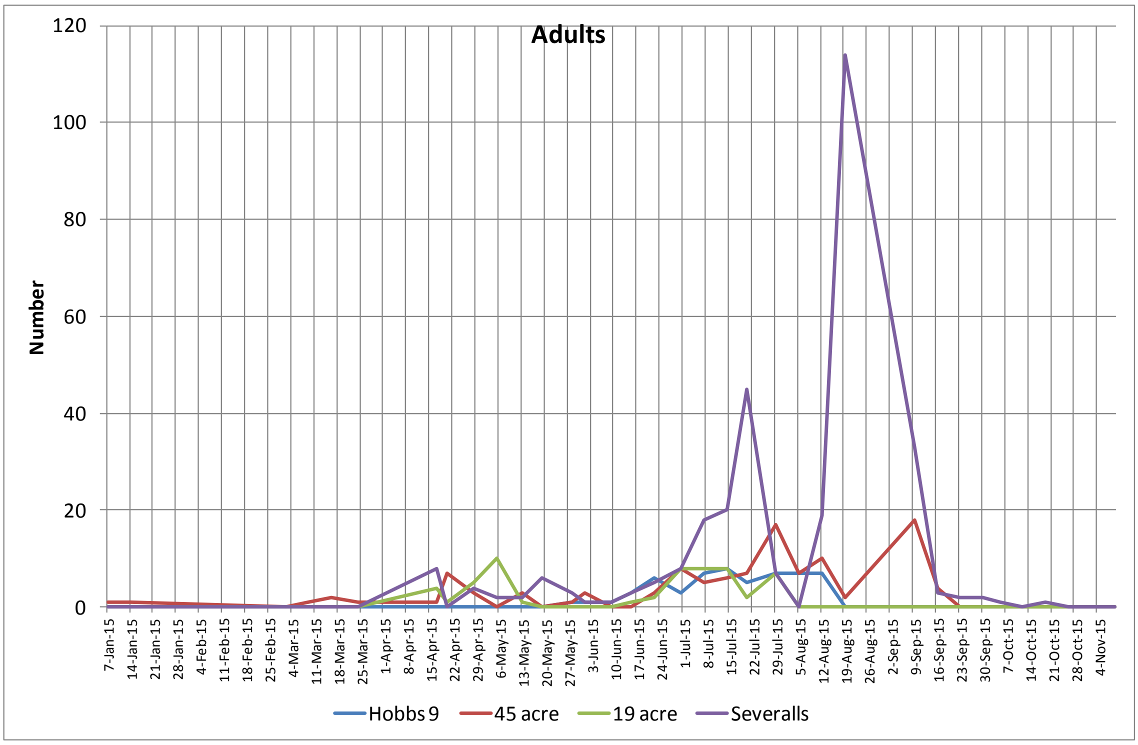

Figure 1.13. Numbers of adults (*Orthops* spp.*)* in samples from the vegetation surrounding organic crops of celery at G's in 2015 (data provided by E. Witkowska).

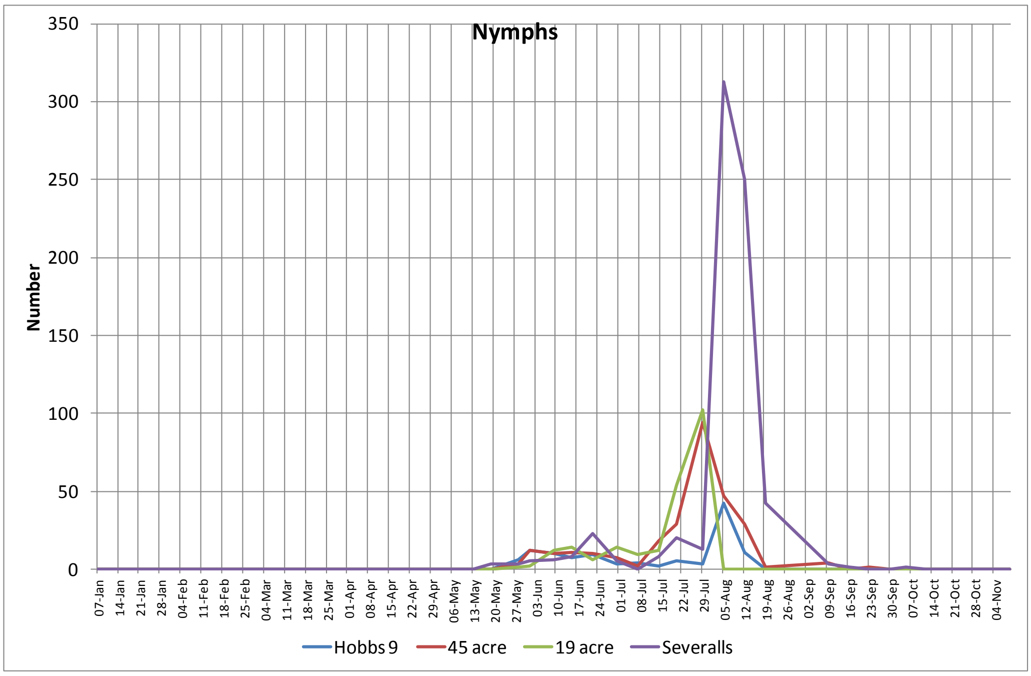

Figure 1.14. Numbers of nymphs (identification not verified) in samples from the vegetation surrounding organic crops of celery at G's in 2015 (data provided by E. Witkowska).

Figures 1.15 and 1.16 summarise captures of adults and nymphs in the vegetation surrounding organic crops of celery at G's in taken by Ela Witkowska in 2016. There are potentially 3 'peaks' in activity for both adults and nymphs.

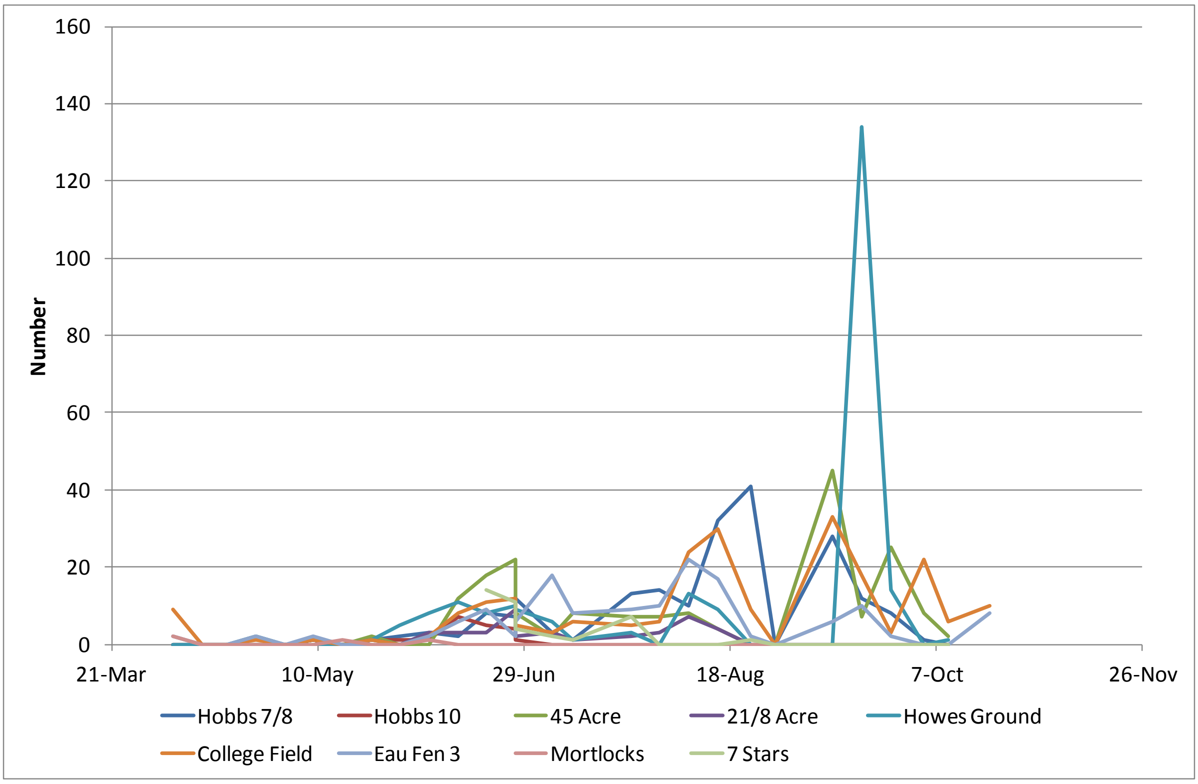

Figure 1.15. Numbers of adults (*Orthops* spp.) in samples from the vegetation surrounding organic crops of celery at G's in 2016 (data provided by E. Witkowska).

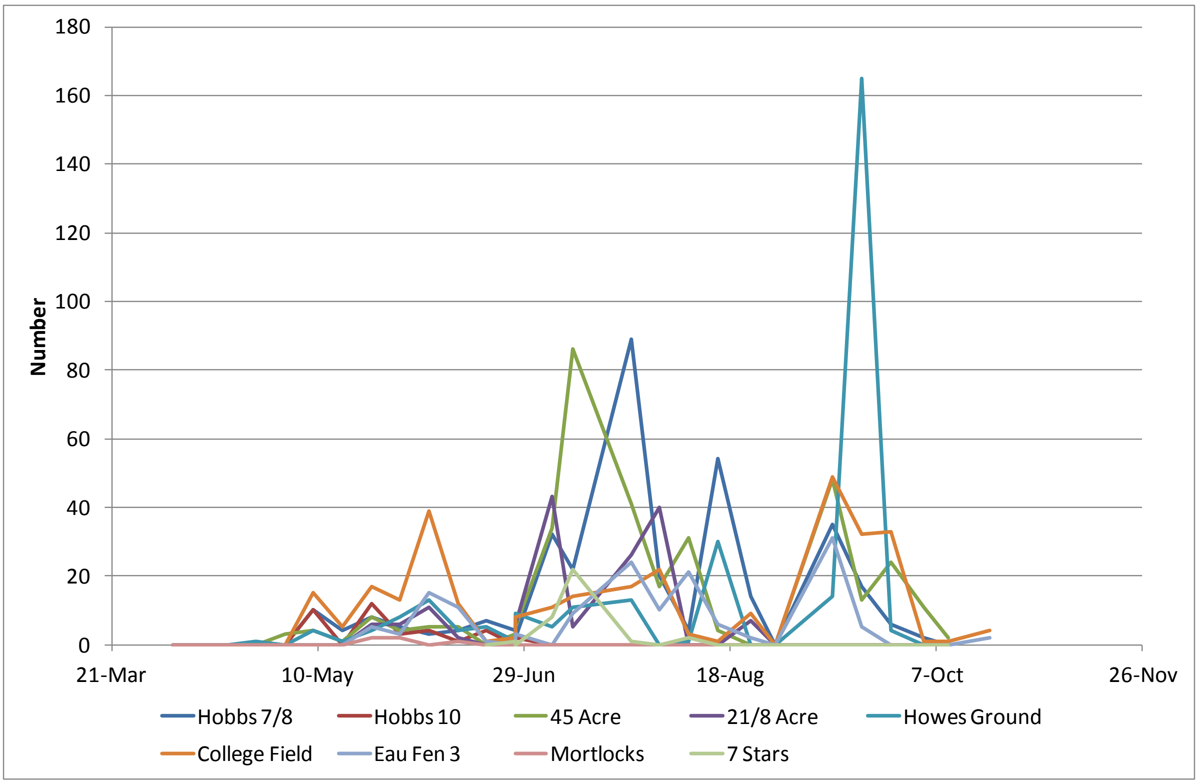

Figure 1.16. Numbers of adults (*Orthops* spp.*)* in samples from the vegetation surrounding organic crops of celery at G's in 2016 (data provided by E. Witkowska).

Figure 1.17 shows a summary of the total numbers of adults found versus date in 2014, 2015 and 2016. The first adults of the year were found close to 3 June 2014, 7 January 2015 and 22 April 2016. However, sampling started quite late in 2014, so the first appearance of adults would have been missed. In addition, in 2015, relatively small numbers of adults were found prior to the end of April and in both 2015 and 2016 the first relatively large numbers of adults were found around 22 April.

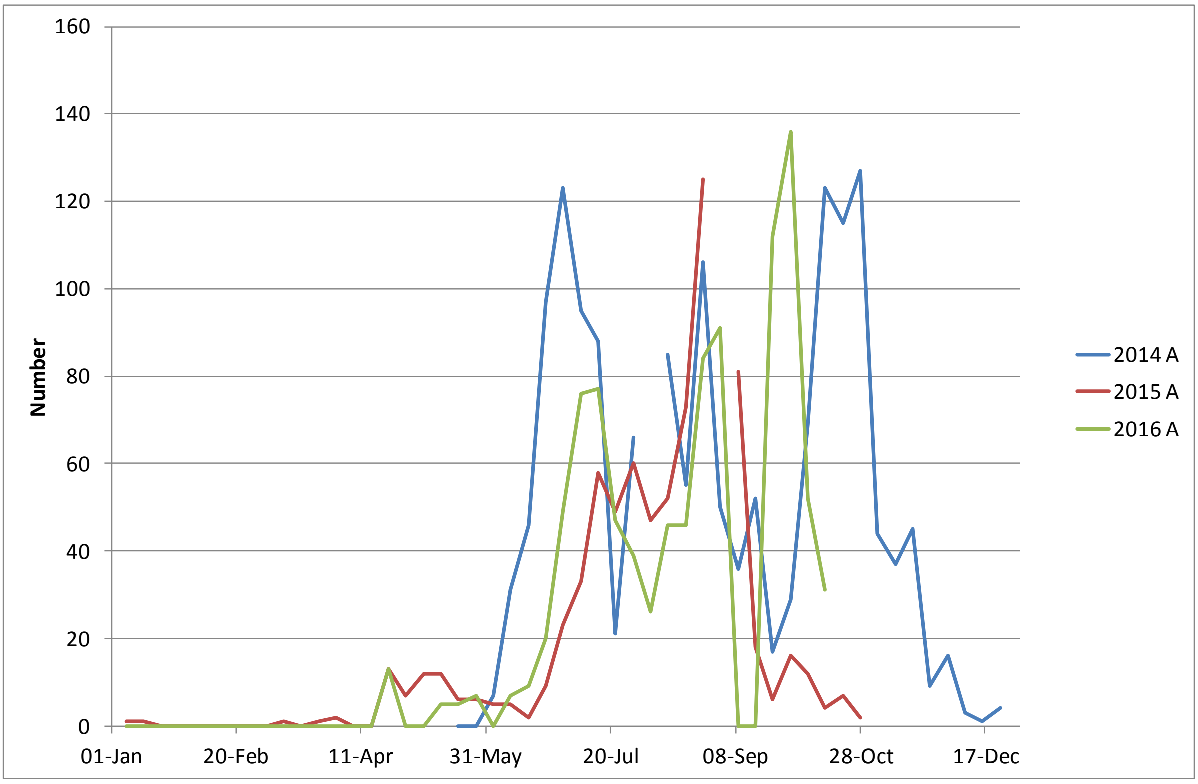

Figure 1.17. Numbers of adults (*Orthops* spp.*)* in samples from the vegetation surrounding organic crops of celery at G's in 2014-2016 totalled across locations (data provided by E. Witkowska).

Figure 1.18 shows a summary of the total numbers of nymphs found versus date in 2014, 2015 and 2016. Obviously these have not been identified to species but it is quite likely that the majority reflect the abundance of *Orthops* spp. The first nymphs were found on 27 May 2014 and 2015 and on 13 May in 2016. The graph suggests that there are 3 periods when nymphs were abundant in each year and the timings of the peaks in the number of nymphs coincide quite closely.

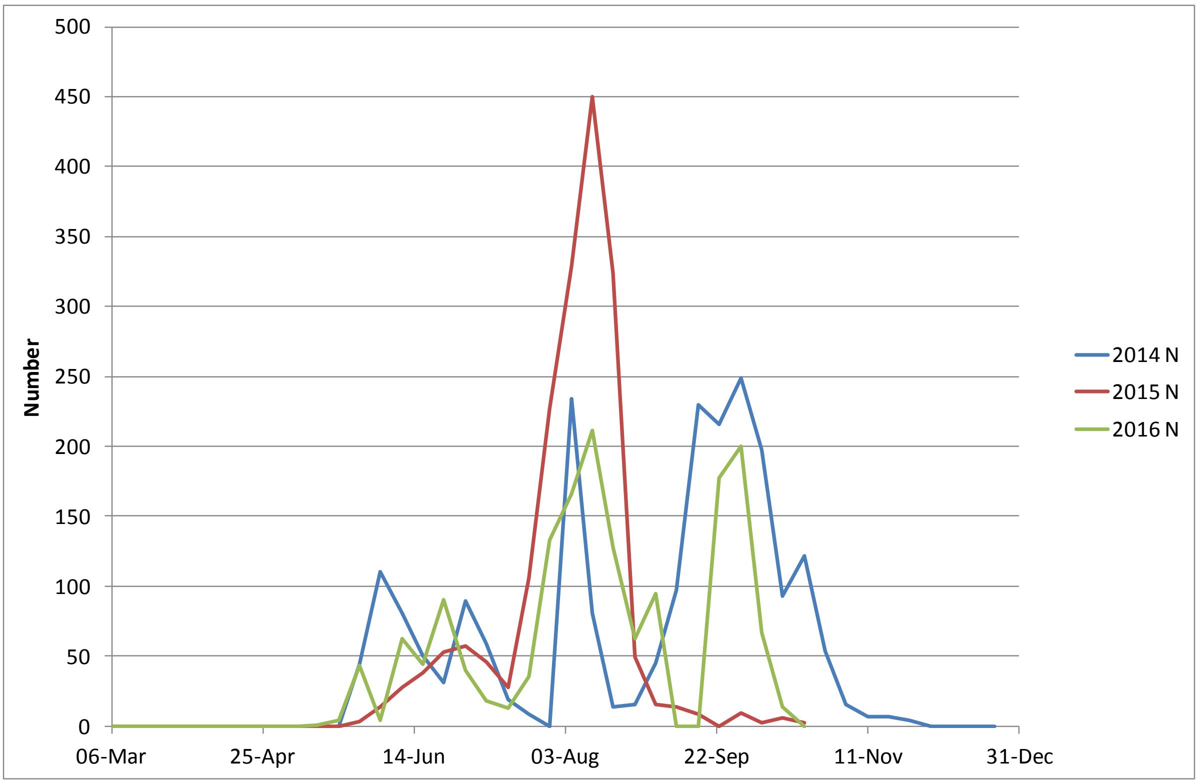

Figure 1.18. Numbers of nymphs (*Orthops* spp.*)* in samples from the vegetation surrounding organic crops of celery at G's in 2014-2016 totalled across locations (data provided by E. Witkowska).

Figure 1.19 compares the early appearance of adult *Orthops* spp. in 2015 and 2016 with the daily maximum temperature. Generally, adults were only found when the maximum temperature was relatively high (e.g. above 10°C) but it is impossible to determine a 'precise' threshold temperature for adult activity.

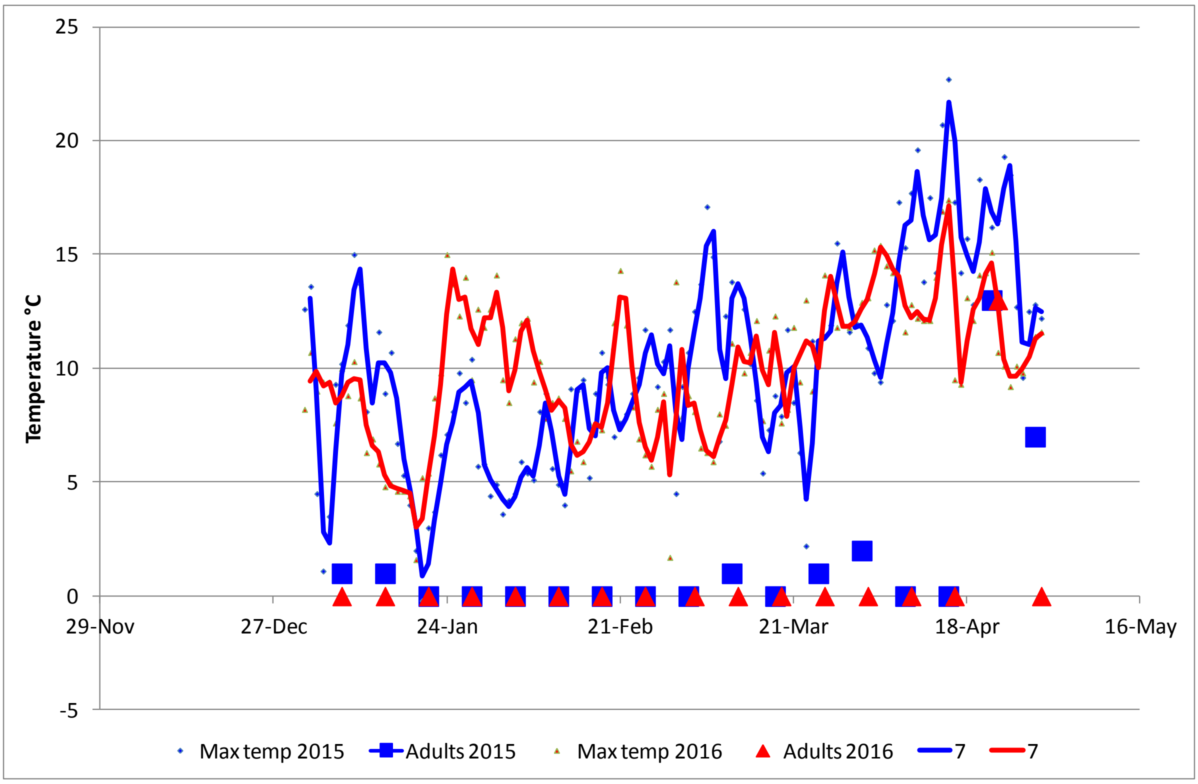

Figure 1.19. This graph compares the early appearance of adult *Orthops* spp. in 2015 and 2016 with the daily maximum temperature (data points and 7-day running means (blue 205; red 2016)).

In the absence of information about a suitable threshold temperature for development of *Orthops* spp., accumulated day-degrees above a threshold of 10°C were estimated using weather data from G's (Barway) – close to where the samples were taken. In addition a threshold of 8°C was used for a second set of estimates based on the use of this threshold in a forecast for European tarnished plant bug (Xu *et al.*, 201). Table 1.5 shows accumulated day-degrees from 1 January each year to each of the 'peaks' in the numbers of nymphs. The third peak occurred at about the same time in all 3 years and the accumulated day-degrees to that date show that 2016 was the warmest summer overall. Bearing in mind the various errors associated with sampling and estimating the date of each 'peak', the day-degree sums for the first two peaks are quite similar (as indicated by a narrow range) but this is not so for the third peak. Overall, the day-degree sums between the peaks for the first and second nymph generation (G1-G2) and second and third generation (G2-G3) are also relatively consistent. This provides the basis for a day-degree forecast for the timing of at least the first and second generations of *Orthops* spp., which would require further field validation before being disseminated widely.

Table 1.5. Dates when nymph populations (*Orthops* spp.) peaked and accumulated day-degrees at Barway, Cambridgeshire from 1 January each year in 2014, 2015 and 2016 above a base of 10°C and 8°C.

Peak	**1**	**2**	**3**	**G1-G2 days**	**G2-G3 days**
2014	17-Jun	05-Aug	30-Sep	49	56
2015	01-Jul	12-Aug	30-Sep	42	49
2016	24-Jun	12-Aug	30-Sep	49	49
	Day-degrees> 10°C from 1 Jan			**G1-G2 day-degrees**	**G2-G3 day-degrees**
2014	259	635	947	376	312
2015	313	616	849	303	233
2016	298	679	1064	381	385
Mean	**290**	**643**	**953**	**353**	**310**
Max	313	679	1064		
Min	259	616	849		
Range	54	63	215		
	Day-degrees> 8°C from 1 Jan			**G1-G2 day-degrees**	**G2-G3 day-degrees**
2014	443	914	1331	471	417
2015	463	842	1160	379	318
2016	450	923	1400	473	477
Mean	**452**	**893**	**1297**	**441**	**404**
Max	463	923	1400		
Min	443	842	1160		
Range	20	81	240		

G = generation

Monitoring activity at Wellesbourne

In the middle of the summer of 2016 it became apparent that the orange sticky traps (Rebell®) used to monitor carrot fly at Warwick Crop Centre were also catching *O. campestris* and so from that point the numbers found on the traps used to monitor carrot fly were recorded (Figure 1.20). Numbers had declined by early September.

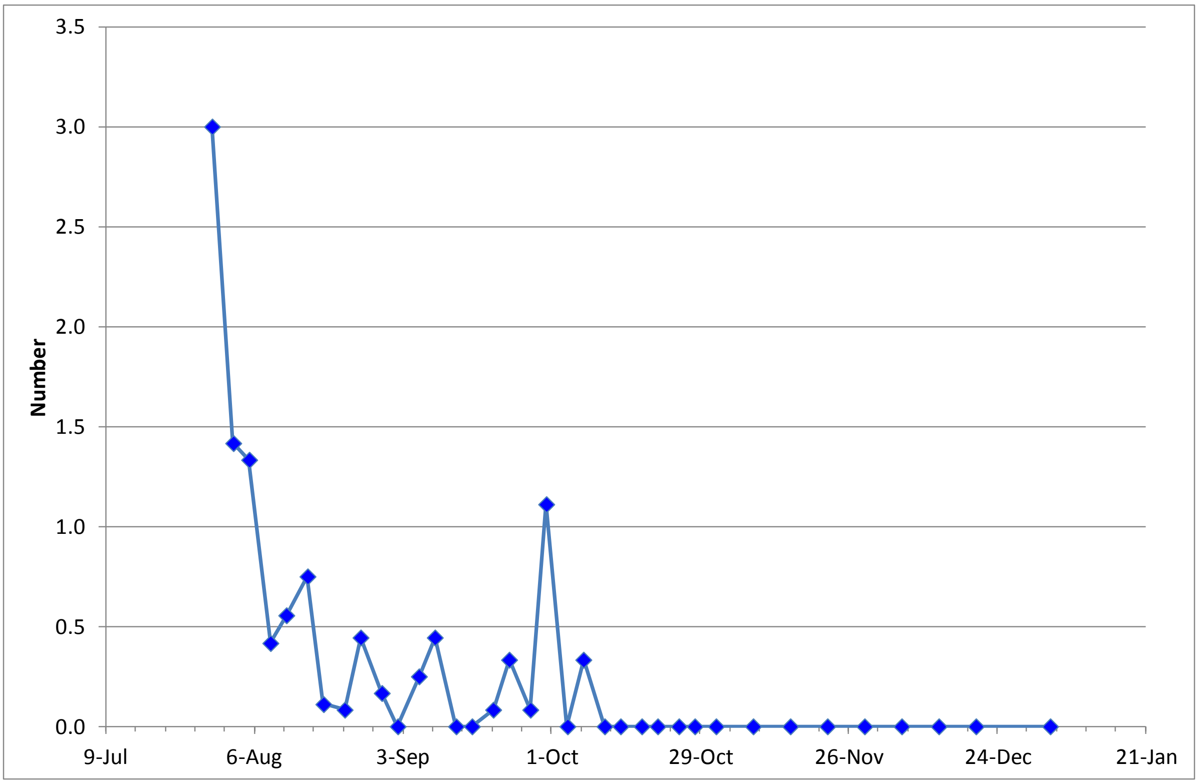

Figure 1.20. Numbers of *Orthops campestris* captured on orange sticky traps at Warwick Crop Centre in 2016 (total on 3 traps).

Crop damage

Damage was seen particularly in the crops of organic celery (Figures 1.21 – 1.24).

Figure 1.21. Damage to organic celery by mirids.

Figure 1.22. Damage to organic celery by mirids.

Figure 1.23. Mirid nymph on organic celery plant.

Figure 1.24. Mirid nymph on organic celery plant.

Crop walking records of mirid presence and damage in G's crops in Norfolk and Cambridgeshire in 2015 are shown in Table 1.6. Damage occurred between early July and the end of August. No damage was observed in 2016.

Table 1.6. Records of mirid damage/activity in crops

Week No.	Week Beginning	Cambridgeshire farms	Norfolk farms
10-27	2 Mar–29 Jun	0	0
28	6 Jul	First mirid and damage seen in organic crops	0
29	13 Jul		First mirid damage recorded Rosedene farm conventional crop
30	20 Jul	More mirid damage found 21/8, N16, N20, conventional crop	More mirid damage found
31	27 Jul	Increasing damage	Increasing damage
32	3 Aug	Less mirids found in crop	
33	10 Aug		Less mirid found in crop
34	17 Aug		
35	24 Aug		
36	31 Aug	No mirid activity in conventional crops Still plenty found in organics	No mirid activity or damage seen
37	7 Sep	Organic crops only	0
38	14 Sep	Organic crops only	0

Other observations

Studies undertaken by Ela Witkowska on the potential to use and manage fine-mesh netting crop covers on celery for control of mirid bugs indicated the following:

- Crop covers effectively exclude *Orthops* spp. if applied after the crop is planted and if well-sealed.
- If the covers are removed then adult *Orthops* spp*.* move rapidly into the crop and are able to move quite a large distance away from the field margin.

- It has not been possible to identify clearly the time of day when dispersal activity is greatest (this would indicate when cultural operations that might affect the integrity of the net barrier could be carried out).

Sampling on and close to potential hosts

More detailed sampling of potential hosts was undertaken in 2016. The bugs are strongly associated with members of the carrot family (Apiaceae). The bugs were abundant on wild carrot (*Daucus carota*) (Figure 1.25) near Wellesbourne but not on the few patches of wild parsnip (*Pastinaca sativa*) (Figure 1.26) found in the locality (supposed to be their preferred host). They were also quite numerous on hemlock (*Conium maculatum*) (Figure 1.27) earlier in the year at G's and have been found on common hogweed (*Heracleum sphondylium***)**. The bugs appeared to aggregate in the vicinity of other apiaceous crop plants apart from celery and were captured on carrot fly traps in carrot plots at Wellesbourne.

Figure 1.25. Wild carrot on the verge of the A429 near the Wellesbourne Campus.

Figure 1.26. Wild parsnip on a verge a few miles from the Wellesbourne Campus.

Figure 1.27. Hemlock at G's.

To investigate the association with Apiaceae in more detail, a total of 20 traps were placed in locations with and without apiaceous hosts – crops and weeds - close to and on the Wellesbourne Campus. Carrot fly traps (Rebell®) were put out on 3 occasions (1-9 August, 9-15 August and 7-11 September October 2016). Totals of 22, 4 and 1 *Orthops* spp. were captured in the 3 sampling periods. The data are summarised in Table 1.7. No *Orthops* spp.

were captured in locations where Apiaceae were absent and the largest numbers were captured close to plots of carrot.

Table 1.7. The numbers of *Orthops* spp. and carrot fly captured on orange sticky traps at Wellesbourne in 2016 (totals for all sampling periods). Means for different 'plant types' in the last 2 columns.

Trap no.	Trap location	Vegetation type	No. carrot fly	No. *Orthops* spp.	Mean no. carrot fly	Mean no. *Orthops* spp.
7	LMW	Carrot	65	10		
8	LMC	Carrot	24	6		
17	Cottage Field	Carrot	7	0	**32.0**	**5.3**
10	Wharf Ground, western boundary	No Apiaceae	1	0		
13	Orchard	No Apiaceae	1	0		
15	Sheep pens	No Apiaceae	0	0		
16	Mushroom Unit	No Apiaceae	0	0		
19	LMC - bulbs	No Apiaceae	2	0		
11	Pump ground	No Apiaceae	2	0	**1.0**	**0.0**
2	A429 Wellesbourne roundabout	Wild Apiaceae	3	3		
4	Cottage Field by stream	Wild Apiaceae	4	1		
6	LMW copse	Wild Apiaceae	6	0		
12	Soakwaters, eastern boundary	Wild Apiaceae	3	2	**4.0**	**1.5**

1	A429 Opposite gateway	Wild Apiaceae - dead	5	0		
3	Pond	Wild Apiaceae - dead	1	2		
5	Townsend	Wild Apiaceae - dead	1	1		
9	LMW	Wild Apiaceae - dead	3	0		
14	Gallas Leys	Wild Apiaceae - dead	15	2		
18	Trees by black hut	Wild Apiaceae - dead	5	0		
20	Wharf Ground, eastern boundary	Wild Apiaceae - dead	0	0	**4.3**	**0.7**

A similar sampling approach was undertaken in fields at G's and traps were situated in field margins between 18 August and 14 September 2016. Very few *Orthops* spp. were recovered. The data are shown in Table 1.8.

Table 1.8. The numbers of *Orthops* spp. and carrot fly captured on orange sticky traps at G's in 2016.

Site no.	Field	Border /trees	Adjacent weeds	Adjacent crop	Vegetation type	No. *Orthops* spp.	No. carrot fly
1	Rose	Poplar trees	Nettle	Celery	Apiaceae	1	8
2	Rose	Drain & reeds	Grass	Celery	Apiaceae	0	1
3	70ac A	Hawthorn & Elder	Nettle	Celery	Apiaceae	0	1
4	70ac A	Poplar trees	Apiaceae	Celery	Apiaceae	0	2
5	70ac B	Poplar trees	Apiaceae	Celery	Apiaceae	0	3
6	50ac	Mixed trees	Apiaceae	Green bean	Apiaceae	1	2
7	Porters	Mixed trees	Apiaceae	Green bean	Apiaceae	2	1
8	Vics	Mixed trees & Elder	Apiaceae	Stubble	Apiaceae	1	0
9	Paddys	Hawthorn & Elder	Grass	Stubble	No Apiaceae	0	0
10	Parson	Poplar trees	Nettle	Maize	No Apiaceae	2	56

At Wellesbourne there appeared to be an association between the presence of *Orthops spp.* and carrot fly, which is not surprising. This suggests that proximity to, and management of, apiaceous weeds will be a key factor. At G's there was some evidence of a similar association between the presence of *Orthops* spp. and carrot fly, although this, and the relationship with the surrounding vegetation, were not so clear, partly because of the low numbers of *Orthops* spp. recovered.

Sampling wild carrot

On 24 August, 50 maturing seed heads of wild carrot (Figure 1.28) on the verge of the A429 near the Wellesbourne Campus were sampled to determine the distribution of mirid adults and nymphs. Previous sampling had indicated that flower heads and dried seed heads were much less preferred by the bugs. The data are shown in Figure 1.29. Almost all seed heads contained one individual at least and some contained several.

Figure 1.28. Maturing seed heads of wild carrot

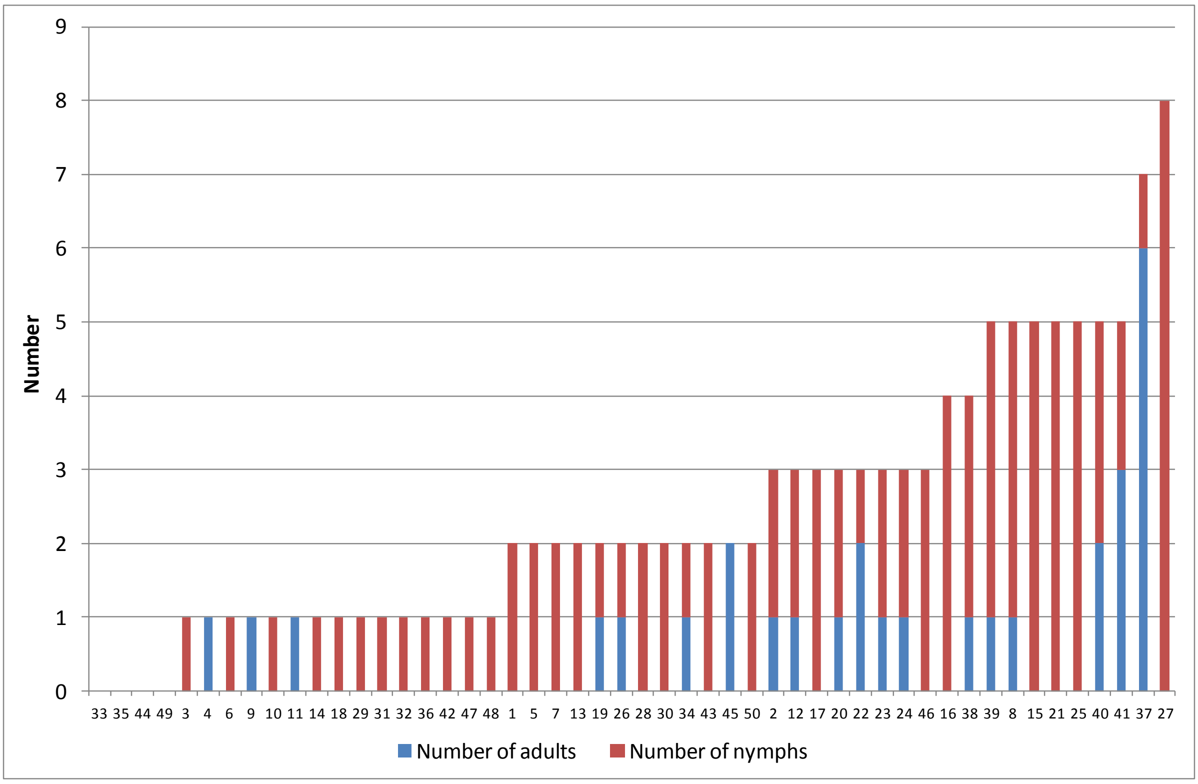

Figure 1.29. Numbers of mirid adults and nymphs (adults were principally *Orthops* spp.) in maturing seed heads of wild carrot on the verge of the A429 near the Wellesbourne Campus.

Objective 2 Once the key species have been identified, determine the feasibility of rearing them in the laboratory or under semi-field conditions, so that more detailed studies can be undertaken on their life-cycle and on methods of control.

Materials and methods

Large numbers of mirids were collected in early August 2015 by shaking the flower heads of wild apiaceous host plants at G's into Bugdorm® cages (43 x 43 x 43 cm). Further samples were collected in late August. The cages and their contents were taken back to the Insect Rearing Unit at Warwick Crop Centre and placed in a controlled environment room at 15°C. As the insects had been collected in a non-selective way, the cages contained many species of invertebrate including spiders and ladybirds. As many as possible of the non-target species were removed from the cages initially. Potential food plants for the target species (*O. campestris*) were then placed into each cage and these included organic celery heads purchased in a supermarket, potted celery plants grown at Warwick Crop Centre and the foliage and flowers of wild Apiaceae. This was initially wild carrot (*Daucus carota)* followed by hogweed (*Heracleum sphondylium*) in late winter – early spring, followed by the foliage of cow parsley (*Anthriscus sylvestris*). Seeds of wild carrot and wild parsnip (*Pastinaca sativa*) were also sown in pots. The wild carrot germinated and these pots were placed in some of the cages. The food material was replaced as necessary. Over time *Orthops* spp. were moved to new cages by selectively removing them with a pooter.

Diurnal periodicity of activity

In 2015, the behaviour of the caged *Orthops* spp. kept at 15°C was observed over time. At any moment a proportion of the adult *Orthops* spp. were on the 'ceiling' of the cage, suggesting that they were displaying dispersal behaviour. The opportunity was taken to observe the diurnal periodicity of the adults i.e. whether a greater proportion were on the ceiling of the cage at any particular time during the day. It was impossible to count all the *Orthops* spp. in any cage so this was a relative estimate. The photoperiod in the controlled environment room was 12L:12D initially (lights on at 05:00 h) and observations (counts of numbers on the cage ceilings) were made under these conditions (records made 3-17 December), it was then altered to 16L:8D (lights on at 05:00 h) to see how this affected the periodicity of activity (records made 18-28 January).

2016

Further insects were collected in 2016 from in and around the Wellesbourne Campus and again kept in cages in the Insect Rearing Unit at Warwick Crop Centre in rooms at 15, 18 and 20^{o}C. Cages were set up on different occasions depending on when adults were collected or became available once batches had been removed for other work (Table 2.1). The bugs were supplied with a wide range of food including potted apiaceous plants e.g. celery and coriander and wild Apiaceae – flowers and foliage, particularly wild carrot. Numbers in each cage were monitored using the approach developed in 2015 to observe the periodicity of activity i.e. the numbers on the ceiling of each cage were recorded in the middle of the day (around noon) – when activity was greatest. This provides a relative estimate of abundance; there appeared to be no other 'non-destructive' way of observing abundance over time.

Table 2.1. Dates when cages of mirid bugs were set up in Insect Rearing Rooms for observations on survival over time.

Cage no.	Room no.	Temp	Cage setup	Adult no. (at setup)
14	5	15°C	Adults collected earlier	Not recorded
1	5	15°C	05/08/2016	30
2	5	15°C	16/08/2016	30
3	5	15°C	31/08/2016	30
9	5	15°C	22/09/2016	30
13	5	15°C	22/09/2016	30
15	2	18°C	Adults collected earlier	Not recorded
7	2	18°C	02/09/2016	30
8	2	18°C	02/09/2016	30
10	2	18°C	22/09/2016	30
11	6	20°C	Adults collected earlier	Not recorded
12	3	20°C	Adults collected earlier	Not recorded
5	6	20°C	05/08/2016	30
6	6	20°C	16/08/2016	30
4	3	20°C	31/08/2016	30

Results

2015

The adult *Orthops* spp. were seen feeding, in particular, on the flower heads of the apiaceous weeds in the cages. Initially there were a large number of nymphs in the samples collected from G's. However, these appeared to die quite rapidly. The adult population seemed relatively constant until late December 2015; after this it declined.

Diurnal periodicity of activity

The numbers (averaged over the days when the insects were observed) of *Orthops* spp. on the ceilings of the cages throughout the day are summarised in Figure 2.1 for the 12L:12D and 16L:8D photoperiods respectively. There was a clear pattern in their activity. Under a 12L:12D photoperiod the adults were most numerous on the cage ceilings at 12:00 h and they were most numerous at 14:00 h under a 16L:8D photoperiod. The decrease in maximum numbers between December and January was due to increased mortality.

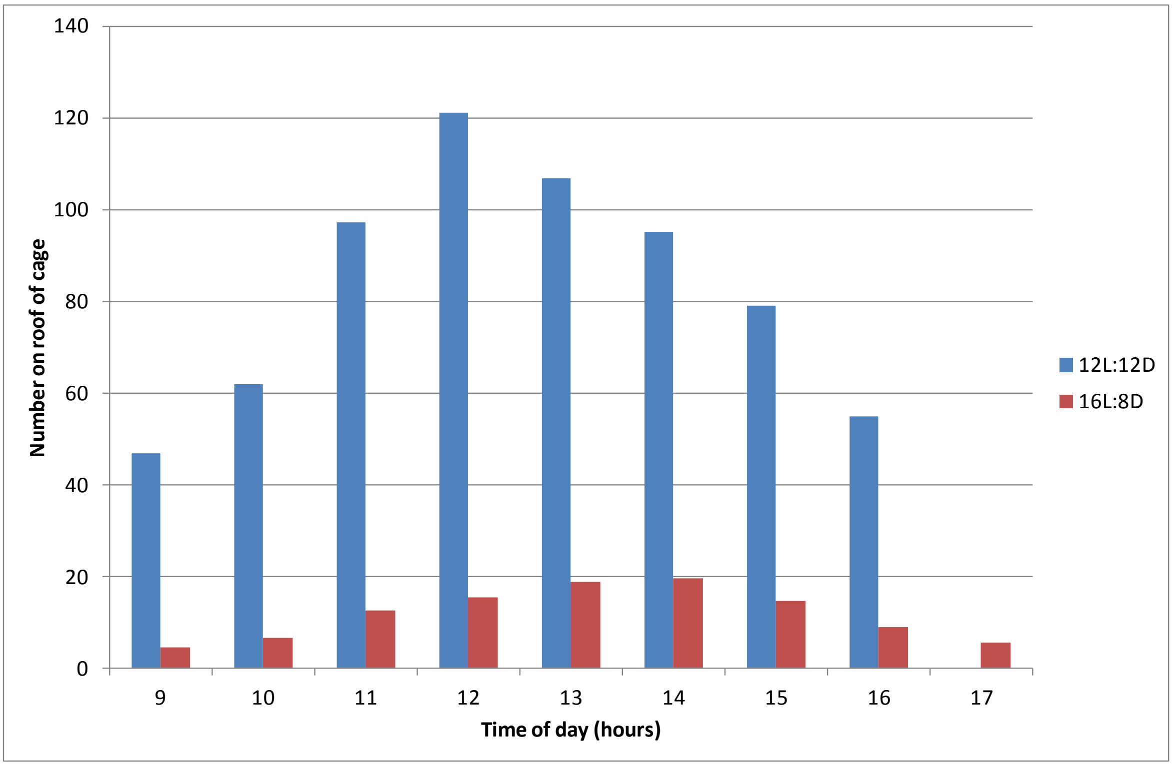

Figure 2.1. Number (averaged over the days when insects were observed) of adult *Orthops* spp. on the ceilings of cages in a controlled environment room at 15°C and 12L12D photoperiod or a 16L:8D photoperiod.

2016

Figures 2.2 – 2.4 show the numbers of adult mirids observed on the ceilings of the cages until numbers had declined to almost zero. In all cases there is evidence of a resurgence in numbers in December, followed by decline in numbers from mid-December onwards. The experimental set-up did not allow us to compare the effect of temperature on the level of activity.

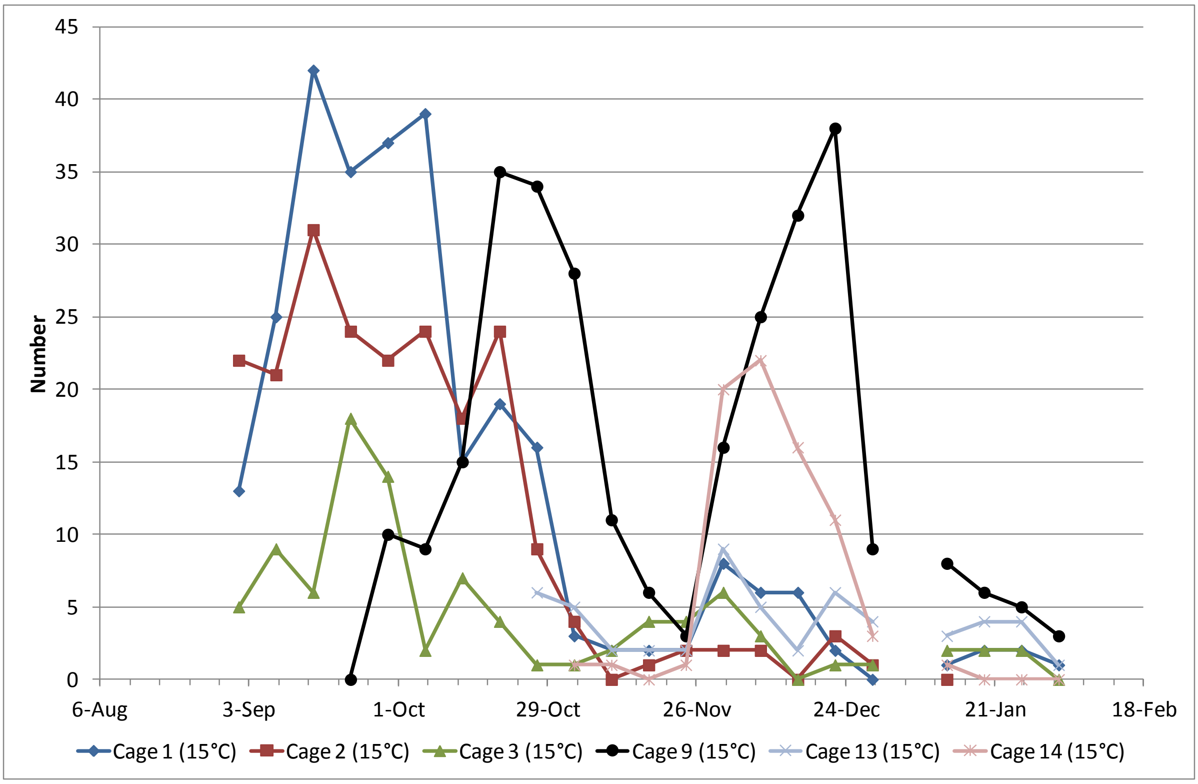

Figure 2.2. Number of adult *Orthops* spp. on the ceilings of individual cages in a controlled environment room at 15°C and a 16L:8D photoperiod.

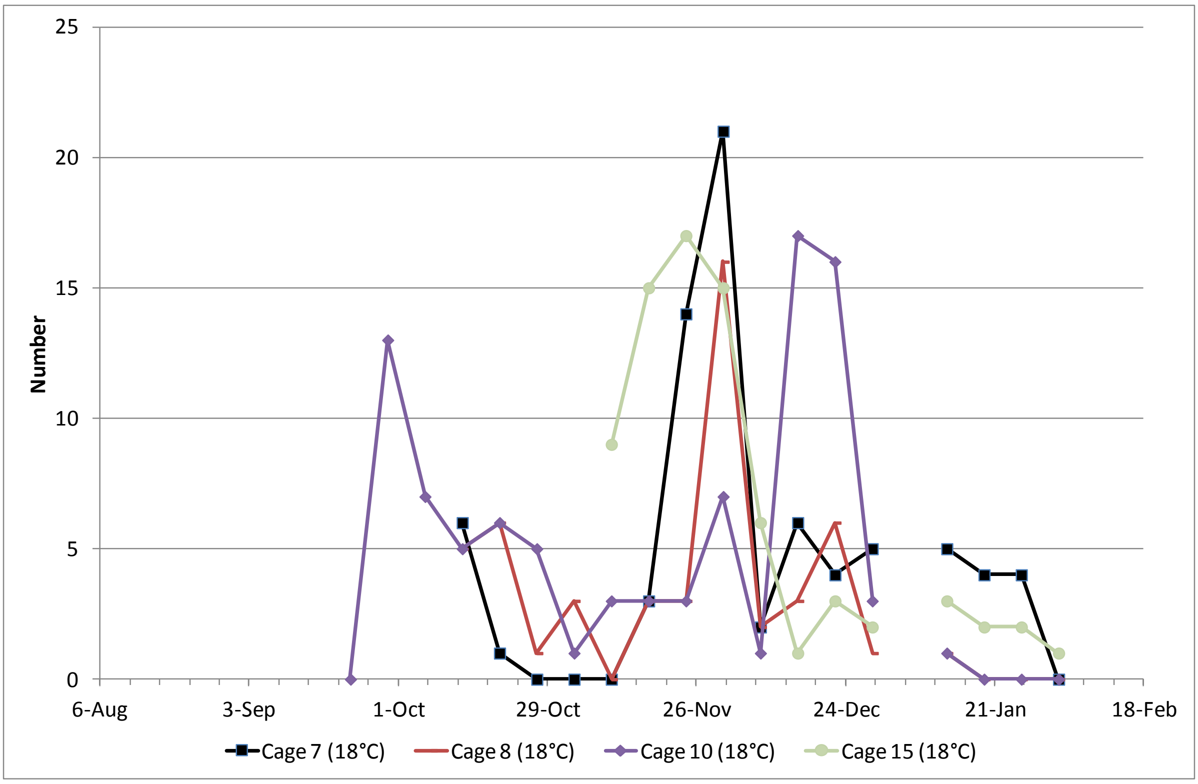

Figure 2.3. Number of adult *Orthops* spp. on the ceilings of individual cages in a controlled environment room at 18°C and a 16L:8D photoperiod.

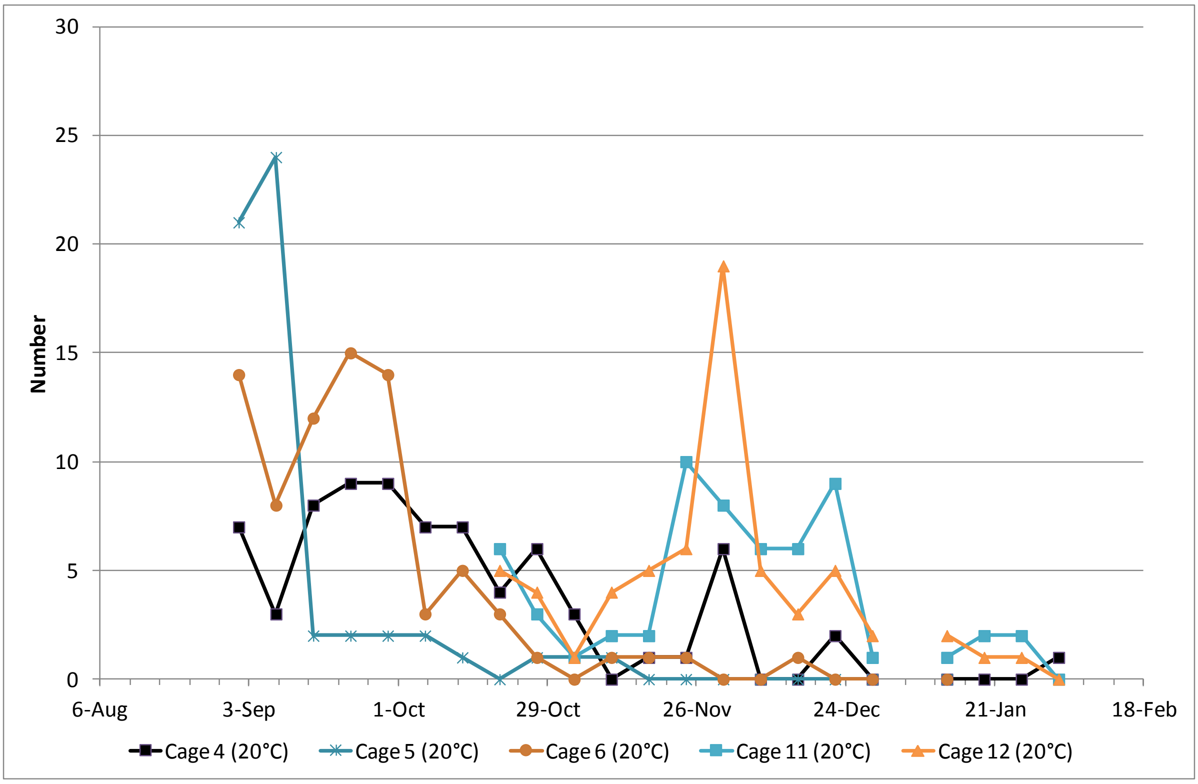

Figure 2.4. Number of adult *Orthops* spp. on the ceilings of individual cages in a controlled environment room at 20°C and a 16L:8D photoperiod.

Objective 3 Using the information from Objective 1, review possible strategies (including the use of insecticides or crop covers) for managing populations of mirid bugs in the vicinity of celery crops.

The 'British Bugs' web site (http://www.britishbugs.org.uk/; Anon., 2016) indicates that *Orthops campestris* is a very common bug throughout the UK, although there seems to be little recent information on its biology. However, there are a number of older publications on *Lygus campestris* (Brittain, 1919; Frohlich, 1960; Handford, 1949; Van Turnhout and van der Laan, 1958; Wheeler, 2001; Whitcomb, 1953) and it appears that this is the same species, which has been re-named as *Orthops campestris*. In these publications *L. campestris* is described as a pest of carrot crops grown for seed production, celery and fennel. Brittain (1919) wrote the following:

'*Lygus campestris*, L., is widely distributed in North America, and is common in Nova Scotia. It has been recorded from Europe and America on Umbelliferae, and in New York on the poison hemlock (*Conium maculatum*). At Truro, Nova Scotia, it has been found on wild parsnip (*Heracleum lanatum*) and the cultivated parsnip (*Pastinaca sativa*). The adults first appear in late June and throughout July, and oviposition begins about a week after emergence, the eggs generally being laid in the grooves of the small stalks bearing the flower-heads. Hatching occurs within a few days and the nymphal stage lasts between four and five weeks, during which five moults occur. The adults, after a short period of activity, seek a suitable shelter for winter quarters, where they remain until the following spring. The injury to the plant is of two kinds, the oviposition punctures on the small stalks bearing the umbels causing the flower-heads to droop, and secondly there is the damage resulting from the feeding punctures of both adults and nymphs, both on the flower-heads and on various other parts of the plant, including the leaf-petioles. In several cases the death of the plants may be caused in this way'.

Forty years later, Van Turnhout and van der Laan (1958), working in the Netherlands, reported that *L. campestris* overwinters in the adult stage and has at least two generations a year. They indicated that the first generation is of minor importance, with the population never being high enough to retard growth of young carrot plants grown for seed. However, they indicated that the second generation could be very injurious as it occurred during flowering and seed ripening. Oviposition began in early July and the first nymphs hatched after 5 days and moulted four times prior to becoming adults. The eggs were 0.7 mm long and found in developing carrot seeds.

A focused review of the literature was undertaken to review possible strategies for managing populations of mirid bugs in the vicinity of celery crops.

Monitoring

Sex pheromones have been studied with regard to *O. campestris* and catches of males have been shown using a mixture of hexyl butyrate (HB), (E)-2-hexenyl butyrate (E2HB), (E)-4-oxo-2-hexenal (4-OHE) and (E)-2-octenyl butyrate (E2OB) found in metathoracic scent gland extracts. This may be useful in monitoring the date of first colonisation in the field using a highly selective sampling method (Yang *et al.,* 2015). In Turkey *O. campestris* have been caught in light traps June-September signalling time of adult activity and showing the potential use of light traps for monitoring adult activity. (Önder *et al.,* 1981)

Control methods

Chemical

Old chemistries such as DDT and Dieldrin have been shown to be very effective in control of *Lygus campestris* with applications increasing seed yields dramatically (Van Turnhout and van Der Laan, 1958), however these non-selective insecticides negatively affect natural enemies and may lead to subsequent outbreaks.

The populations of mirids rarely reach zero after any insecticide applications as the activity of the insecticide lowers after some time and colonisation continues throughout the season. In carrot seed crops the optimal application was 3-4 treatments both for a product based on Neem extract and lambda-cyhalothrin. Three treatments led to a satisfactory level of seed yield increase and increased seed germination. No significant difference was found between the product based on Neem extract and lambda-cyhalothrin in decreasing seed pitting damage (Kolosowski, 2007).

Decis 2.5 EC (deltamethrin) was shown to reduce the populations of mirid bugs in celery and was effective in celery grown for seed and applied at the time of seed maturation. Sadofos 30 (malathion), Winylofos 50 (dichlorvos), Topsin M and Zolone 35 EC (phosalone) all maintained low populations of sucking insect pests. Owadofos 50 (chlorpyriphos), however, was shown not to cause a decline in mirid numbers (Anasiewicz and Winiarska, 1995).

In glass vial bioassays the LC_{50}s were 3.05ppm, 1.63ppm, 0.08ppm, for endosulfan, thiamethoxam and lambda-cyhalothrin respectively. Metaflumizone was ineffective after 24h due to its slow-acting nature; it did however cause mortality after 72h on treated leaf discs. Lambda-cylohathrin was fast acting and highly effective preventing damage to the celery plants, however due to the broad-spectrum nature of this insecticide it is likely to reduce natural enemies (Scott-Dupree *et al.,* 2007). Garlic oil, Kaolin and vegetable oil do not show promising results in control of mirids and are likely to show little impact on *O. campestris.* Azadirachtin (NeemAzal) has been shown to reduce mirid numbers, increase yields of crops and reduce damage and has been shown to be more effective than diflubenzuron and phosalon (Jaastad *et al.,* 2009).

Biological Control

Fungal

Beauveria bassiana has been shown to have high potential to control *Lygus lineolaris* with a number of isolates showing mortality rates above 90% with knockdown times of <5 days. Field trials on application of *B. bassiana* showed significant reductions in populations in strawberry crops along with reductions in fruit damage (Sabbahi *et al.,* 2008). Isolates may also be effective against *O. campestris;* however there is no information available on this topic.

Parasitoids

A number of parasitoids have been shown to reduce populations of mirid bugs in the field. Eggs have been parasitised by *Anaphes fucipennis* and *Erythmelus lygivorus,* with *Anaphes fucipennis* parasitising 10% of *Lygus* eggs on oilseed rape (Varis, 1972). Five species of *Peristenus* are known as parasitoids of *Lygus* in Europe *(P. adelphocoridis, P. digoneutis. P. pallipes, P. rubricollis, P. stygicus)* (Kuhlmann *et. al.,* 2000). Such species have been introduced into Northern America to control *Lygus* on a range of crops, most notably the introduction of *Peristenus digoneutis* has led to significant reduction of *Lygus lineolaris* numbers in forage alfalfa. No parasitoids have been investigated for their potential to control *Orthops campestris;* however the host range of *Peristenus* is varied (Haye *et al.,* 2005) and *O. campestris* is likely to support development of the parasitoid.

Populations of *Lygus lineolaris* and both an egg parasitoid and nymphal parasitoid were found in Quebec. *Telenomus* was the most numerous parasitoid throughout the season and had strong synchrony with mirid populations showing good potential for population control in the field (Al-Ghamdi *et al.,* 1995).

Predators

Big-Eyed bug (*Geocoris spp.*), damsel bug (*Nabis spp.*), minute pirate bug (*Orius tristicolor*) and species of spider are common predacious arthropods on herbaceous mirid bugs (Hagler *et al.,* 1992; Wright *et al*., 2013*). Coccinella spp.* Syrphids and lacewing are known to prey on nymphs (Varis, 1972). These predators are unlikely to completely suppress populations but conserving these natural enemies is likely to contribute to population regulation. In natural vegetation where populations of mirid bugs build, natural enemies are not effective in preventing large numbers of adults from migrating into the crops (Fleisher and Gaylor, 1987). Active adult mirids are less impacted by predators due to their mobile nature (Chaney *et. al. 1999;* Zink and Rosenheim, 2008).

Encouraging natural enemies in the surrounding vegetation may contribute to the suppression of *Lygus* populations; however little evidence exists for this to occur on a field crop scale (Rämert *et al.,* 2005).

Physical

Management of insect pests in celery and potato crops by pneumatic removal – using field scale vacuums has been investigated. Significant population reductions of *Lygus lineolaris* have been achieved using Biovac® (Vincent and Lachance, 1993). Although populations have been shown to be reduced by vacuum machines, the damage to the crop was often still unacceptable (Pickel *et al.*, 1994). Removal of *Lygus* on strawberry crops by vacuums can occur during daylight hours leaving nocturnal generalist predators within the crop, such as carabids (Vincent *et al.,* 2003). There is often a requirement for weekly vacuuming of crops to actively control the pest populations below the level that can cause economic damage (Weintraub *et al.,* 1996)

Cultural

Wild host plants

Orthops campestris has been shown to have largest populations in flower strips that are approximately 2 years old – with young and older strips supporting significantly smaller populations and with populations corresponding with high numbers of Apiaceae (Ullrich, 2001). *Heracleum mantegazzianum* has been shown to support populations of *O. campestris* (Hansen *et al,* 2006) and is likely to provide sites for overwintering prior to migration onto crops in June. Weed management is therefore likely to reduce numbers of mirid pests in the vicinity of crops by limiting overwintering sites; such methods have been used to control mirid pests of cotton in the USA (Snodgrass *et al.,* 2006). This provides potential for area wide pest host management in the surrounding areas of vulnerable crops (Fleisher and Gaylor, 1987)

Host plant resistance

Polygalacturonases (PG) seem to be common in Miridae and it is these chemicals that appear to be the cause of damage to plants (Shackel *et al.,* 2005). Plant polygalacturonase-inhibiting proteins (PGIPs) may deactivate the PGs of mirid bugs, preventing damage caused from feeding, leading to a method of resistance. This have been shown for bean PGIPs (Frati *et al.,* 2006) as well as alfalfa and cotton PGIPs (Shackel *et. al.,* 2005). Herbivory by mirid bugs may induce two different types of plant defence, direct through PGIPs and indirect through volatile synomones (a chemical, emitted by an organism, which mediates interspecific interactions in a way that benefits an individual of another species which receives it, and the emitter), bringing in parasitoids. This may provide a good basis for producing plants with greater resistance against insects and attracting natural enemies into the crop (Frati *et al.,* 2006). Such methods of resistance could be important in the development of new resistant varieties of celery if such approaches are viable commercially.

Objective 4 Evaluate products approved currently for application to celery and novel insecticides and bio-insecticides that might be used to control mirid bugs in small-scale field trials and undertake a small scale study of potential biocontrol agents (predators).

Efficacy of insecticides on Orthops spp. – *field trial*

Preparations were made to undertake a small field trial at G's in one of the conventional celery crops in both 2015 and 2016. This was to evaluate insecticides, including those approved currently on celery, as there is no information about the efficacy of any of these treatments. The proposed treatments are shown in Table 4.1. Approved insecticides are lambda-cyhalothrin, pirimicarb, pymetrozine and spinosad. Unfortunately an infestation of sufficient size to collect robust data did not occur in either year.

Table 4.1. Treatments proposed for small-scale field trial in conventional celery crops at G's.

Treatments			Hectare rates	
	Product	**Active ingredient**	**Rate**	**Water l/ha**
1	Tracer	spinosad	200	400
2	Plenum	pymetrozine	400	400
3	Dynamec	abamectin	480	400
4	Hallmark zeon	lambda-cyhalothrin	50	400
5	Biscaya	thiacloprid	400	400
6	Movento	spirotetramat	500	400
7	Experimental			400
8	Untreated			400

Efficacy of insecticides and bioinsecticides on Orthops spp. – *laboratory trial*

Materials and methods

A laboratory trial was undertaken to compare foliar spray treatments (9 treatments and untreated control). Potted celery plants (cv Granada) sown in November 2015 and overwintered in a poly tunnel were used for the trial. By the time of spraying all plants were flowering or had seed heads. Before spraying the plants were cut to allow placement in insect cages (approx. 43 x 43 x 43 cm). The trial was replicated in time with 2 replicates of 9 treatments arranged in a randomised block design. All treatments were assessed on two occasions except Treatment 7 (Pyrethrum) which was only assessed on the second occasion (4 replicates). In total each treatment was replicated 4 times. The trial was conducted within the Insect Rearing Unit (IRU) at Warwick Crop Centre.

Mirids (*Orthops* spp.) were collected in the weeks preceding the trial from wild carrot seed heads found growing on the verge of the A429 adjacent to Warwick Crop Centre. The mirids were maintained in cages containing celery, wild carrot and cow parsley plants within the IRU. Test plants were taken outside and the treatments (Table 4.2) were applied using a knapsack sprayer fitted with 02F110 nozzles in 200 l/ha water. The plants were then placed in cages (one plant per cage) and ten adults were added to each cage. The cages were kept at 20°C and the numbers of live mirids were assessed 1, 2, 3 and 6 days after spraying. The key events are listed in Table 4.3.

Table 4.2. Treatments used in spray trial

Code	Active ingredient	Product	Rate	Approved for use on celery
1	HDCI 104		As specified by supplier	No
2	HDCI 098		As specified by supplier	No
3	Lambda-cyhalothrin	Hallmark	0.05 l/ha	Yes
4	HDCI 105		As specified by supplier	No
5	HDCI 106		As specified by supplier	No
6	Pymetrozine	Plenum	0.4 l/ha	Yes
7	Pyrethrins	Pyrethrum 5EC	1.1 l/ha	Yes
8	HDCI 107		As specified by supplier	No
9	Spinosad	Tracer	0.2 l/ha	Yes
10	Untreated			

Table 4.3. Key events in spray trial

Date	Event
16-Aug	Plants sprayed, adults introduced
17-Aug	Adults assessed 1 day after spraying
18-Aug	Adults assessed 2 days after spraying
19-Aug	Adults assessed 3 days after spraying
22-Aug	Adults assessed 6 days after spraying
27-Sep	Plants sprayed, adults introduced
28-Sep	Adults assessed 1 day after spraying
29-Sep	Adults assessed 2 days after spraying
30-Sep	Adults assessed 3 days after spraying
6-Oct	Adults assessed 6 days after spraying

Results

The percentage live adults (after Angular transformation) were analysed. Each assessment was analysed separately. All analyses were carried out using Analysis of Variance (ANOVA) in the statistical package 'Genstat'. The analyses were interpreted using treatment means together with standard errors for the differences (SED) between means and associated 5% least significant differences (LSD).

The data was analysed in two ways. In the first analysis of each variable all 10 treatments were included and the differences between the two occasions were ignored, considering the overall experiment to have been arranged following a Completely Randomised Design. This is necessary to allow the inclusion of Treatment 7 (Pyrethrum 5EC - only tested in second trial). In the second analysis of each variable Treatment 7 was excluded and a block term was included to allow for differences between the two occasions. These analyses show that there is no evidence for differences between occasions (variance ratios are all much smaller than 1.00), and so only the first analysis is presented (Table 4.4)

Analyses of data collected on Day 2 ($p = 0.028$), Day 3 ($p < 0.001$) and Day 6 ($p < 0.001$) were significant. The percentage live adults declined over time but none of the treatments were very effective. Two days after spraying only lambda-cyhalothrin had reduced the percentage live adults compared with the untreated control. Three days after spraying HDCI

098, HDCI 105 and HDCI 107 had also reduced the percentage live adults compared with the untreated control and this pattern was repeated 6 days after spraying. Reduction in the percentage live adults due to spinosad was nearly significant 3 and 6 days after spraying. There was little difference between the effective treatments but 6 days after spraying HDCI 098 had reduced the percentage live adults significantly compared with HDCI 105.

Table 4.4. The mean percentage live adults of *Orthops* spp., 1, 2, 3 and 6 days after spraying.

Treatments	**1 day**		**2 days**		**3 days**		**6 days**	
	Ang	Back trans	Ang	Back trans	Ang	Back trans	Ang	Back trans
HDCI 104	85.4	99.4	90.0	100	85.4	99.4	80.8	97.4
HDCI 098	72.1	90.6	62.1	78.2	48.5	56.2	24.2	16.8
Lambda-cyhalothrin	56.6	69.7	5.01	63.9	50.0	58.7	44.3	48.7
HDCI 105	65.2	82.5	63.8	80.5	57.7	71.4	48.2	55.5
HDCI 106	73.4	91.8	80.8	97.4	78.8	96.2	61.2	76.8
Pymetrozine	67.5	85.4	69.5	87.8	69.5	87.8	60.9	76.3
Pyrethrins	90.0	100	85.4	99.4	85.4	99.4	76.2	94.3
HDCI 107	75.6	93.8	64.3	81.2	43.3	47.1	31.7	27.6
Spinosad	78.8	96.2	70.5	88.8	59.0	73.4	50.9	60.2
Untreated	80.8	97.4	78.9	96.2	78.8	96.2	74.1	92.5
F-value	1.93		2.51		4.95		5.23	
P-value	0.086		0.028		<0.001		<0.001	
SED	10.06		10.36		10.12		11.70	
5% LSD	20.54		21.17		20.66		23.89	
df	30		30		30		30	

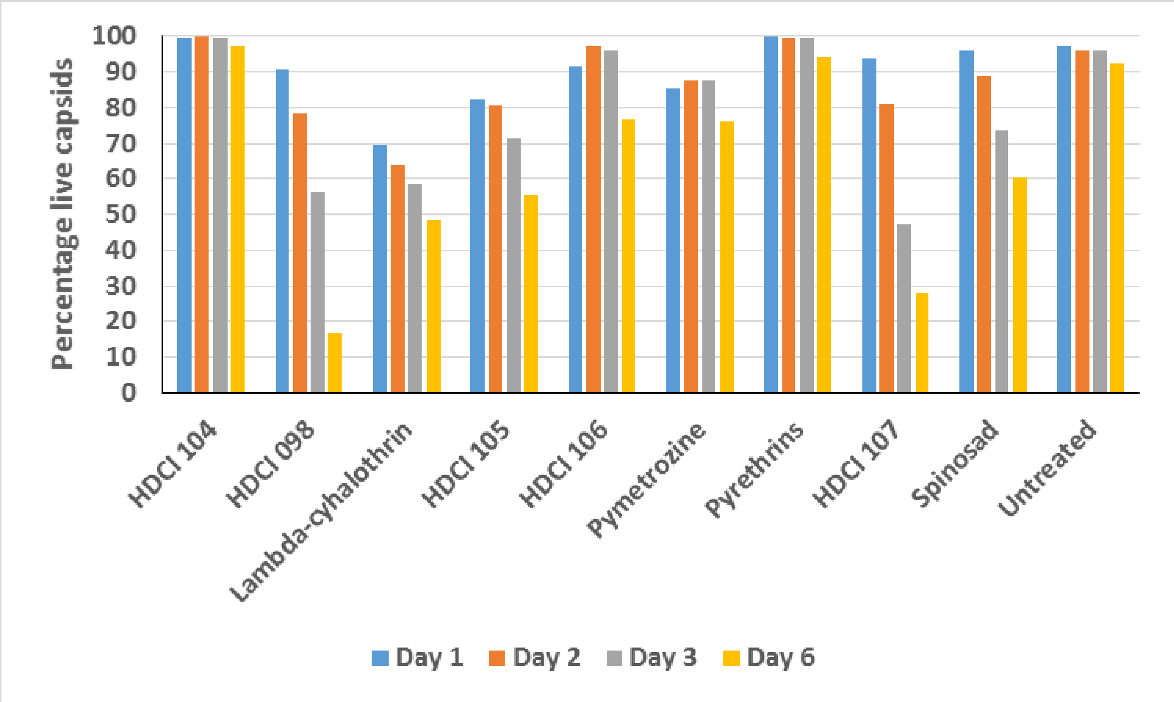

Figure 4.1. The mean percentage live mirids (adults) 1, 2, 3 and 6 days after spraying.

Potential for natural enemies to reduce infestations of Orthops spp.

A study was conducted to assess the impact of various predatory natural enemies (NEs) on the survival of *Orthops* spp. under controlled laboratory conditions. Two types of natural enemies were considered: ‘commercially-available’ and ‘wild-caught’, where the former could potentially be released, particularly early in the season at overwintering sites, and the latter could potentially be encouraged by habitat management, in an attempt to reduce populations of the pest.

Initially it had been hoped that mirid eggs might be available to allow screening on all life stages, i.e. eggs, juveniles and adult mirids. This was, however, not possible, with attempts to induce oviposition under culture-room conditions being unsuccessful at both Warwick Crop Centre and STC. (Culture attempts at STC involved holding adults at 20°C, 16:8 light:dark cycle, providing fresh wild carrot flowers, organic celery stems and 50:50 honey solution absorbed on cotton wool. Juveniles were seen to mature under these conditions, but no ‘new’ generation was observed). Consequently, screening was conducted on juveniles and adults only, as sourced from wild populations present collected from wild hosts near the Wellesbourne Campus by staff at Warwick Crop Centre.

It is worth noting that assessments on eggs might be expected to yield a greater opportunity for identifying effective biological control agents, allowing for inclusion of egg parasitoids. A short review of the online literature identified several species of parasitic Hymenoptera that would be of potential interest. *Anagrus atomus*, for example, is a species of parasitoid wasp that attacks leafhopper eggs. Adults could potentially parasitise mirid eggs, with *Anagrus atomus* previously available through BCP Certis as Anagsure [http://www.bcpcertis.co.uk/products/biological-control/insects-and-mites/detail/article/anagrus-atomus.html], though sourcing may now be an issue following BCP's merger with Koppert. *Peristenus* spp. also hold potential for mirid control, as previously noted, having been released around the globe to attack *Lygus* nymphs. The species *P. digoneutis* and *P. relictus* both appear to be native to Europe, though do not appear to be readily available commercially. Scope may nevertheless exist to encourage such parasitoids under field conditions through provision of favoured habitat, e.g. in field margins (see FV 334). Finally, nematodes and entomopathogenic pathogens may hold potential for treating mirid pests, though were not included here.

Screening method

Three individual experiments were conducted, as detailed below. Natural enemies for screening were selected based on pre-existing knowledge regarding their potential to predate on true bugs. Screening of wild-caught natural enemies was conducted in two stages; an initial screen run in a non-replicated manner informed natural enemy selection for a second, replicated screen of selected natural enemies to provide data for analysis.

Screening experiments were conducted within Petri dishes in a controlled temperature room. A pre-determined number of adult and juvenile mirids were placed within each dish with a section of organically grown celery and a small piece of cotton wool soaked in 50% honey solution to provide sustenance and moisture. Natural enemies and commercially-available biocontrols were then introduced at pre-determined rates and mortality of the mirids and natural enemies was measured 4 days after predator introduction.

Initial screening of wild-caught natural enemies

Five adult and five juvenile mirids were introduced into each Petri dish for the purposes of this initial screening, followed by the respective natural enemies. The impact of the wild-caught natural enemies was assessed initially at 24 hours post their introduction, but only very low levels of mirid predation were observed. As a result the screening was run for a further 3 days before a final assessment of mirid mortality was made. Subsequent screenings all assessed mortality of mirids and natural enemies at 4 days. The naturally-occurring predators selected in the initial screening consisted of web forming spiders, ladybirds, soldier beetles, earwigs, sawflies, pirate bugs, damsel bugs, harvestmen and lacewing larvae.

Screening of commercially-available natural enemies

Three commercially-available biocontrol agents, supplied by Koppert UK, were selected for screening based on the likelihood of possible predation of juvenile or adult mirids. These consisted of *Macrolophus pygmaeus* (Mirical-N), *Orius strigicollis* (Thripor-S) and *Atheta coriaria* (Staphybug). On the date of receipt, the commercially-available natural enemies were introduced into each Petri dish together with five adult and five juvenile mirids, with five replicates conducted for each species. Ten natural enemies were introduced per Petri dish for *Macrolophus* and *Orius* and five per Petri dish for *Atheta.* Again, an assessment of mortality of mirids and natural enemies was made after 4 days.

Further screening of wild-caught natural enemies

Based on the results of the initial screening of wild-caught natural enemies, further samples of the more promising natural enemies were collected and used to conduct a replicated screening using web-forming spiders, hunting spiders, earwigs, damsel bugs and harvestmen. The numbers of wild-caught natural enemies available at the time of screening dictated their numbers per Petri dish and did not strictly reflect the numbers used in the initial screening, although a sufficient number were sourced to allow for four replicates with each natural enemy. Very few juvenile mirids were available when commencing this experiment and as a result only adult mirids were introduced to the Petri dishes. Again, an assessment of the mortality of mirids and natural enemies was made after 4 days.

Statistical analysis

Initial screening data for wild-caught natural enemies were not suitable for statistical analysis. Remaining data (for further testing of wild-caught natural enemies and commercially-available natural enemies) were replicated and analysed using Kruskal-Wallis tests as they could not be considered parametric. *Post-hoc* testing was undertaken using pairwise Mann-Whitney tests where main effects were shown to be statistically significant at $P < 0.05$. All analysis was undertaken in Minitab v17.

Results

Initial screening of wild-caught natural enemies

The mortality of mirids in 'control' treatments (in the absence of natural enemies) was relatively low and less than 10% (Table 4.5). Though unsuitable for statistical analysis, screening indicated higher mortality of mirids in dishes containing web-forming spiders, earwigs, damsel bug spp. and harvestmen, and to a lesser extent ladybirds, soldier beetles and lacewing larvae. Addition of sawflies or pirate bugs to dishes had no apparent effect on mirid survival. Based on these results, a selection of wild-caught natural enemies were selected for further, replicated screening.

The potential for spiders and earwigs to feed on mirids was evident. Damsel bugs were variably effective, depending upon the species (with larger species appearing more voracious as in Figure 4.2). Encouragingly, the most effective natural enemies all appeared to feed on adult mirids as well as juveniles. Nevertheless, as juvenile mirids were relatively late stage when used, and matured during the course of the study period in some dishes, it was not possible to reliably separate out which stage had been attacked.

Table 4.5. Percentage of mirids (adults and juveniles) killed by wild-caught natural enemies 4 days after introduction of natural enemies.

	No. natural enemies per dish and (no. replicates)	**% overall mortality***	**Further testing?**
Control	0	7	Y
Web forming spider	3 & 4 (2)	60	Y
Ladybird adult	3 & 5 (2)	30	N
Soldier beetle	4 (1)	30	N
Earwig	4 (1)	70	Y
Sawfly	4 (1)	10	N
Pirate bug	7 (1)	10	N
Damsel bug spp	1 (3)	47	Y
Lacewing larva	1 (1)	30	N
Harvestman	5 (1)	80	Y

*of adults and juveniles combined

Figure 4.2 Damsel bug, tentatively identified as a tree damsel, feeding on adult mirid.

Screening of commercially-available natural enemies

As in the previous experiment, the mortality of mirids under control conditions was low (Table 4.6). As juvenile mirids were available at a younger stage than previously, a more reliable investigation could be made into predation of the different stages of development. In general, juveniles were preferred to adults by all natural enemies tested, and particularly by *Orius* and *Atheta*. Statistical analysis confirmed a significant difference between treatments for juvenile mortality ($H_{(3)}$ = 10.45; P = 0.015), but not for overall mortality ($H_{(3)}$ = 6.35; P = 0.096) or adult mortality ($H_{(3)}$ = 2.83; P = 0.418). *Post-hoc* testing of juvenile mortality data indicated significant differences ($P < 0.05$) between the control and the treatments with *Orius* and *Atheta*. No other significant differences between pairs of treatments existed, though the difference between the control and the *Macrolophus* treatment approached significance (P = 0.059).

Table 4.6. Percentage of mirids (adults and juveniles) killed by commercially-available natural enemies 4 days after introduction of the natural enemies.

	No. natural enemies per dish and (no. replicates)	**Percentage mortality of mirids**		
		Overall	**Adult ***	**Juvenile**
Control	0	6 ± 0.04	-4 ± 0.07	16 ± 0.04
Macrolophus	10 (5)	20 ± 0.09	4 ± 0.15	36 ± 0.07
Orius	10 (5)	30 ± 0.03	8 ± 0.05	52 ± 0.08
Atheta	5 (5)	26 ± 0.07	-8 ± 0.08	60 ± 0.11

*of adults and juveniles combined

Further screening of wild-caught natural enemies

As in the previous experiments, mirid mortality remained relatively low (10%) under control conditions. Spiders and field damsels both appeared to reduce numbers of adults. However, the data were highly variable and a Kruskal-Wallis test failed to identify a statistically significant difference between treatments ($H_{(5)} = 8.54$; $P = 0.129$).

Earwigs and harvestmen did not cause a significant level of mortality in this experiment. It is worth noting that this further screening was conducted on adult mirids only, and with relatively fewer natural enemies per dish for these two species than used previously.

Table 4.7. Percentage of mirids (adults and juveniles) killed by commercially-available natural enemies 4 days after introduction of the natural enemies.

	No. natural enemies per dish and (no. replicates)	**% adult mortality**
Control	0	10 ± 5.8
Web forming spider	1 (4)	35 ± 20.6
Hunting spider	1 (4)	25 ± 12.6
Earwig	2 (4)	0 ± 0
Field damsel	2 (4)	25 ± 12.6
Harvestman	1 (4)	0 ± 0

Although the results of the experiments suggest that both commercially-available and wild-caught natural enemies will feed on mirids, particularly nymphs, the experiments were run in small confined chambers with high predator: pest ratios, promoting a high level of contact between them. The potential of certain natural enemies, whilst suggested by these results, can only be confirmed with further study under field conditions. This would be especially true for *Atheta*, which are unlikely to encounter *Orthops* spp. under field conditions due to spatial separation, but were nevertheless included to indicate the potential of predatory beetles. Nevertheless, despite the limitations of *in vitro* screening, the results obtained are still potentially encouraging in that they confirm a range of species will feed on mirids, including commercially-available species that could, in principle, be mass released against this pest, particularly if 'hotspots' or 'high-risk' habitats (e.g. overwintering sites or areas of non-crop habitat with high host plant density) could be identified. As previously noted, further potential for biological control of *Orthops* spp. may exist within the hymenopteran egg parasitoids.

Survival of natural enemies over the 4-day course of the experiments was relatively high (c. 60% or above) for all species tested, with the exceptions of harvestmen and sawflies. Though harvestmen were tested in larger arenas than other species, it is possible that the size and/or high activity level of these species led to high mortality under *in vitro* conditions. For certain natural enemy species, i.e. *Orius*, spiders and earwigs, survival was 100%.

There are a number of management measures available to encourage populations of 'wild' natural enemies including spiders and earwigs (margin management for spiders, artificial refugia for earwigs). Nevertheless, concerns regarding the potential pest status of earwigs would need to be addressed prior to recommending that this species be encouraged in the vicinity of celery. Spiders were particularly numerous in maturing seedheads of wild carrot sampled for mirids.

Objective 5 Determine the potential and significance of improved monitoring and forecasting of infestations by mirid populations.

Orthops campestris is a very common species that has a preference for apiaceous crops. Although the literature describes it as completing one or two (or possibly more) generations in different parts of the world, this study suggests that there are three generations of nymphs each year and that, as described by others, *O. campestris* overwinters as an adult. The most effective method of monitoring *Orthops* spp. in field margins appears to be through tapping/shaking foliage onto a large plastic tray and rapidly recovering/counting insects that land on the tray. Celery crops provide an additional challenge in terms of sampling, which almost inevitably must be destructive and involves either shaking an uprooted plant into a bag or taking the plant apart as quickly as possible *in situ*. In the present study the use of sticky traps was investigated and this may be a promising approach for monitoring activity when populations are high. Whether such traps could be used to determine the risk of damage to crops would require further research, with a large amount of replication to be confident in any threshold indicated.

Any approach to indicate the timing of activity could be useful in terms of targeting treatments; there certainly appears to be some potential to use the sampling approaches described above and also to use day-degrees for guidance. As both adults and nymphs cause damage to the crop there is a risk of damage throughout the summer. However, the later generations appear to be more abundant and potentially more damaging and so an indication of their timing may be useful.

Objective 6 Identify promising approaches that could be investigated in a subsequent project.

Netting covers

This study and G's own observations and activities have indicated two potential approaches to management, the first is the use of crop covers made of fine mesh netting to exclude all stages of *Orthops* spp. Ela Witkowska has undertaken a number of small-scale experiments in commercial organic crops and has demonstrated that this approach successfully excludes the bugs, although it may have other consequences. For example, the presence of the covers may exacerbate infection by pathogens such as celery late blight, *Septoria apiicola,* and reduce crop quality. The use of crop covers also presents challenges for effective weed control, is expensive and labour intensive. However, this approach is particularly important for organic crops where there are currently no effective control options; the trial addressing Objective 2 confirmed that pyrethins are ineffective against adult *Orthops* spp.

Management of vegetation in field margins

This study has confirmed the significance of wild Apiaceae in sustaining populations of *Orthops* spp. and the strong association between their presence and the presence of the pest. This indicates that management of vegetation in field margins may be one of the most effective ways of reducing the abundance of this pest. One approach is to mow field margins (which is not selective for Apiaceae) but this would also have to include dykes where species such as hemlock occur. Another approach could involve selective removal of apiaceous weeds rather than removing all species; which might have adverse consequences for wild life. Again it would be interesting to investigate whether sticky traps could be used to indicate 'risk' of damaging infestations occurring.

Novel control agents

Although it has not been possible to rear *Orthops* spp. on a continuous basis, and the reasons for this require further research, it does appear feasible to collect adults in large numbers and maintain them over reasonable periods to evaluate control methods in a laboratory setting. Thus it should be feasible to screen other potential control agents as they arise and it may be possible to do this within SCEPTREplus. It would be good to determine a method of producing nymphs or sustaining field-collected nymphs over longer periods so that these could also be tested.

Discussion

Orthops campestris is not a 'new' pest and was reported causing damage 100 years ago (Brittain, 1919). However, its significance has increased recently in relation to celery production in the UK and particularly the production of organic celery. This is likely to be because the production system has favoured the development of large populations of the pest in the vicinity of the crops. In the case of organic celery, prior to use of crop covers, this would have provided an ideal habitat for the pest to develop since although crop rotation is practiced the organic land is in a single 'block' and the spatial separation of 'new' from 'old' crops is not great. It is apparent that there is a strong association between the presence of *O. campestris* and members of the Apiaceae and that a number of wild and cultivated species are suitable hosts. Generally *Orthops* spp. adults were found in maturing seed heads of wild and some cultivated hosts; it is not clear what they were feeding on in the carrot plots at

Wellesbourne where there were no flowers/seed heads. The significance of *O. campestris* as a pest may also have increased because of the emphasis on managing field margins for non-target species. Wild Apiaceae are common and are good sources of nectar and pollen for a wide range of species.

As described previously, sampling confirmed that *O. campestris* overwinters as an adult and it is likely that mortality over winter is considerable, as for European tarnished plant bug (Varis, 1972). This is supported by field monitoring data at G's which indicate that numbers of adults (and the subsequent nymphs) are at their lowest early in the spring and that the later generations of adults and nymphs cause more damage. Whilst it is likely that both nymphs and adults are subject to predation by a range of natural enemies, conditions in and around organic crops in particular are likely to be favourable for population increase. Whilst it was unclear after the first year of field work whether there were two or three generations per year, the monitoring data from margins surrounding organic crops provide clearer evidence of three generations per year. The day-degree sums from 1 January to peak numbers of first and second generation nymphs appear remarkably consistent, although the day-degree sum to the third generation is more variable, which might be related to the influence of day-length on the occurrence of adult diapause. There is too little information to tell. It would not be possible from field data to estimate the 'best' threshold temperature for the accumulation of day-degrees as day-degree sums above any pair of thresholds are so highly correlated. The only way to estimate the threshold would be through experimental work in the laboratory should it become possible to rear *O. campestris*.

It was disappointing that it was not possible to establish a continuous culture of *O. campestris* and that whilst the field-collected adults survived for some time, in both years the population died out in the New Year. This suggests that these adults were in the overwintering state (diapause) and that they eventually ran 'out of steam', before laying eggs, as they were kept at much higher temperatures than they would experience in the winter in the field. It is certainly possible that they require exposure to lower temperatures before mating and egg-laying will occur (normally in the following spring). Again, further work would be required to understand what is happening. Two approaches might be rewarding in future; firstly sampling adults earlier in the year when they were definitely not in diapause and trying to establish a culture from these and/or secondly, exposing later-collected adults to low temperatures in an attempt to break diapause. Diapause in European tarnished plant bug is also poorly understood (Xu et al., 2014).

It appeared that populations of *Orthops* spp. were lower in conventional crops than organic crops and this may be due to the different rotations employed. It may also be due to the use of pesticides in conventional crops, even if not directly for control of mirids. For example, lambda-cyhalothrin is applied to control carrot fly and in the past deltamethrin has also been applied for this purpose.

Whilst the insecticides tested did not appear to provide a high level of control very rapidly, it is likely that nymphs would be more susceptible than adults, if only due to their smaller size. In addition, in the laboratory trials, for practical reasons of retaining the insects, it was necessary to apply the treatments to the plants prior to infesting them with the mirids. In a field situation then it is certainly possible that treatments would contact the mirids directly and that their exposure to insecticides would be increased.

G's have demonstrated that fine mesh netting can be used effectively to exclude mirid bugs from celery crops. It is not clear whether destruction of wild hosts would obviate the need for net covers and over what scale this would need to be carried out. There is evidence from G's that the adults are very mobile but there have been no studies to determine dispersal range.

Conclusions

Key conclusions are:

- The pest species causing damage to celery crops are principally *Orthops campestris.*
- The presence/abundance of *Orthops campestris* is strongly associated with apiaceous host plants. This suggests that removal of wild *Apiaceae* from field margins may reduce infestations.
- *Orthops campestris* overwinters as an adult in field margins and it is most likely that it completes three generations per year.
- There appears to be a relatively consistent day-degree requirement between generations.
- Lambda-cyhalothrin and three insecticides not approved currently on celery had activity against adult *Orthops* spp.
- The results of experiments suggest that both commercially-available and wild-caught natural enemies will feed on mirids, particularly nymphs.

Knowledge and Technology Transfer

An article was prepared for The AHDB Grower magazine.

A Factsheet is planned.

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