Project title:	Celery: Investigation of strategies to control capsid bugs in outdoor crops
Project number:	FV 441
Project leader:	Rosemary Collier, University of Warwick
Report:	Annual report March, 2016
Previous report:	None
Key staff:	David Norman, David George, Andrew Jukes, Marian Elliott
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):	15 April 2017

DISCLAIMER

While the Agriculture and Horticulture Development Board seeks to ensure that the information contained within this document is accurate at the time of printing, no warranty is given in respect thereof and, to the maximum extent permitted by law the Agriculture and Horticulture Development Board accepts no liability for loss, damage or injury howsoever caused (including that caused by negligence) or suffered directly or indirectly in relation to information and opinions contained in or omitted from this document.

The results and conclusions in this report are based on an investigation conducted over a one-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.

[Name]

[Position]

[Organisation]

Signature .... Date ....

[Name]

[Position]

[Organisation]

Signature .... Date ....

Report authorised by:

[Name]

[Position]

[Organisation]

Signature .... Date ....

[Name]

[Position]

[Organisation]

Signature .... Date ....

CONTENTS

GROWER SUMMARY

Headline

The capsid bug *Orthops campestris* has been confirmed as the pest insect causing damage to celery crops in eastern England. This species appears to feed mainly, or possibly entirely, on wild and cultivated members of the carrot family (Apiaceae).

Background

Capsid 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 capsid damage in celery suggest that the status of capsids as pests of this crop is increasing, particularly in organic crops. Three species of capsid have been seen in the vicinity of infested celery crops: common green capsid (*Lygus pabulinus*), European tarnished plant bug (*Lygus rugulipennis*) and what appeared to be *Orthops campestris* (and has now been confirmed in this project as the main pest in celery crops), which does not have a common name. Crop invasion by capsids is unpredictable and relatively little is known about their biology, particularly the biology of *O. campestris*, 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 capsids in celery relies on the use of a small number of generally broad-spectrum synthetic insecticides. In organic crops, control is reliant on the use of mesh covers, which work well if applied at the right time and they are 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.

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

Summary

The specific objectives of this project are to:

1. Develop a clearer understanding of the identity and life cycles of the key species of capsid 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 capsid 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 capsid 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 capsid populations.
6. Identify promising approaches that could be investigated in a subsequent project.

Only objectives 1, 2 and 4 will be covered in this report on the first year of the project.

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

Sampling celery crops and field margins

Sampling of field margins was carried out at 4 sites where celery was grown starting 1 April 2015 until 28 September and thereafter at fortnightly intervals until 7 December. The margins of an additional site where celery was not grown were also sampled. 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 capsid was caught it was placed in a pot with alcohol and labelled with location and date. Further samples were collected from field margins surrounding organic crops by Ela Witkowska from G's (Figure 1). 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.

Crop sampling was also carried out regularly in the organic celery crops once activity started, for around 4-6 weeks per site, whilst the crop was at the right growth stage to be attractive to capsids. Five plants per week from an uncovered area were carefully pulled up

and shaken into an insect proof bag and capsids were collected. The occasional capsid found in conventional crop walking was also captured and saved in pots with alcohol.

The most abundant species of capsid was identified as *Orthops campestris* and this identification was verified by Joseph Botting an expert on plant feeding bugs. Once the identity of *O. campestris* had been confirmed, the samples collected in alcohol were identified. Only *O. campestris* adults were found in the crop samples between July and September. Damage was seen particularly in the crops of organic celery between early July and the end of August. Adult *O. campestris*, 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 capsids from the samples from the field margins were nymphs (70%). Some of these at least (from their size) appeared to be common green capsid nymphs. Figure 1 compares the abundance of adults and nymphs in samples from field margins in 2014 and 2015. The data suggest that there may have been three 'peaks' in the numbers of nymphs in 2014 and two in 2015. Estimation of accumulated day-degrees above a base of 6°C from 1 January each year indicated that 2014 was warmer overall than 2015 and the 'difference' was about 2 weeks.

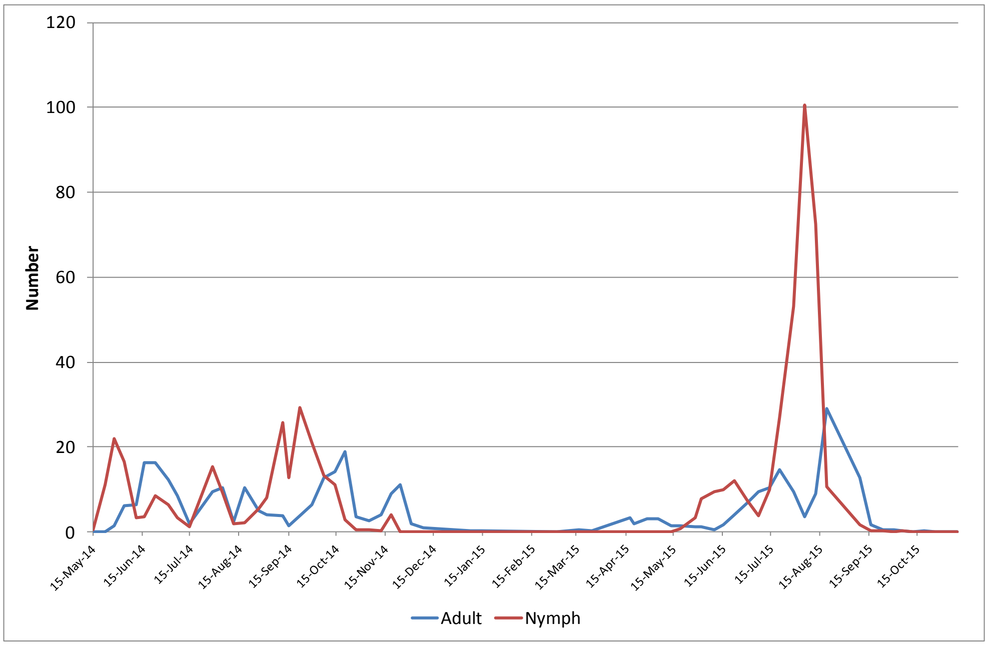

Figure 1. Numbers of adults (*O. campestris)* and nymphs (identification not verified) sampled from the vegetation surrounding organic crops of celery at G's in 2014-2015 (data provided by E. Witkowska).

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 capsids were collected at G's in early August 2015 by shaking the flower heads of wild apiaceous host plants into Bugdorm® cages (30 x 30 x 30 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 the *O. campestris* were moved to new cages by selectively removing them with a pooter.

The caged *O. campestris* were observed and the adults were seen feeding in particular on the flowerheads of the apiaceous weeds. 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 but after this it declined. The behaviour of the caged *O. campestris* was observed. At any moment a proportion of the adult *O. campestris* were on the roof of the cage, suggesting that they were displaying dispersal behaviour. The opportunity was taken to observe the diurnal periodicity of this behaviour i.e. whether a greater proportion were on the roof of the cage at any particular time during the day. It was impossible to count all the *O. campestris* in any cage so this was a relative estimate. The photoperiod in the controlled environment room was 12L:12D initially (lights on at 5 am) and observations were made under these conditions (records made 3-17 December), it was then altered to 16L:8D (lights on at 5 am) to see how this affected the periodicity of activity (records made 18-28 January). There was a clear pattern in their activity. Under a 12L:12D photoperiod the adults were most numerous on the cage roofs at 12 noon and they were most numerous at 2 pm under a 16L:8D photoperiod.

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

Preparations were made to undertake a small field trial at G's in one of the conventional celery crops in 2015. This was to evaluate insecticides approved currently on celery as well as additional active ingredients, as there is no information about the efficacy of any of these treatments. Unfortunately an infestation of sufficient size to collect robust data did not occur. Approved insecticides are lambda-cyhalothrin, pymetrozine and Majestik. Pirimicarb was approved but will no longer be available. The same approach will be taken in 2016. However, it seems that it will be more productive to undertake small scale laboratory tests with *O. campestris* collected from the field. It is certainly possible to maintain adults in good condition for a long period of time which means that these are suitable candidates for efficacy trials with both insecticides and bioinsecticides (at Warwick Crop Centre) and predators (Stockbridge Technology Centre).

Stockbridge Technology Centre has drawn up a protocol for small-scale tests of biocontrol agents. The only product specifically for control of capsids is Tigranem (Koppert - unspecified *Steinernema* nematode sp.). Generalist predators, such as ladybirds and lacewings, are likely to be effective. Other natural enemies may not be effective against adults, but may be useful against nymphs and eggs. Potential test organisms that are available commercially are *Tigranem* (Koppert)*, Macrolophus pygmaeus, Coccinella septempunctata, Adalia bipunctata* and *Chrysoperla rufilabris.*

Discussion

Orthops campestris appears to be a very common bug on apiaceous weeds throughout the UK, although there is very little recent information on its biology. However, there are a number of older publications on *Lygus campestris* and it appears that this is the same species and that it has been re-named as *O. campestris*. In the publications on *L. campestris* it is described as a pest of carrot crops grown for seed production, celery and fennel and it appeared to have one generation per year in Nova Scotia and two in the Netherlands. Identification of adult capsids found in celery crops in 2015 showed that *O. campestris* was the only species of capsid found in the crop, although common green capsid and European tarnished plant bug were found in the field margins.

The data obtained to date in the present study confirm that *O. campestris* overwinters as an adult (sampling in 2014 began too late to detect the first period of adult activity). In 2015, where monitoring started in January, adults became more active in mid-April and the first nymphs were found in mid-May. It seems unlikely that this species completes a single generation in the UK and the data from 2015 suggest that there are two generations – as suggested for populations in the Netherlands. The data from 2014 indicate that there might possibly be 3 generations.

All of the host plants mentioned in the literature are members of the Apiaceae. If this is the case then there are opportunities to manage *O. campestris* through managing apiaceous weeds in the vicinity of the crop. This is in contrast to common green capsid and European tarnished plant bug which have a wide range of hosts from a number of plant families.

Large numbers of capsids were captured in August and kept in a controlled environment room at 15°C at Warwick Crop Centre. The nymphs appeared to die very quickly but the adults survived until early January. There was no evidence that they produced young during this period. The simplest explanation is that these adults were in reproductive diapause and that they did not receive the environmental cues to complete diapause and begin to reproduce. The fact that the adults survived so long means that they will be good candidates for efficacy trials in 2016. However it will be important also to test the immature stages although it is likely that the eggs will be inaccessible to control with either insecticides or biocontrol agents.

Work plan for 2016

Further work will focus on the biology and control of *O. campestris*. Key activities will be to:

- Sample the spatial distribution of *O. campestris* on field margins to determine their association with host plants, especially Apiaceae.
- Monitor the phenology of *O. campestris* in crops of celery and in field margins.
- Collect *O. campestris* adults and nymphs as soon as they appear and culture them at high temperatures/long daylengths with apiaceous umbels as one source of food. Determine generation times under these conditions.
- Collect *O. campestris* adults and nymphs to undertake laboratory tests on insecticides, bioinsecticides and biocontrol agents.

Financial Benefits

It is expected that the project will identify the key pest species, provide further information about their biology, and identify ways of improving capsid control. The results will be most applicable to celery producers, but will have cross-sector relevance, particularly for soft fruit producers. Results may also have relevance for the control of other pests sharing a similar biology.

Action Points

There are currently no action points from the first year of this two-year project.

SCIENCE SECTION

Introduction

Capsid 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 capsid damage in celery suggest that the status of capsids as pests of this crop is increasing, particularly in organic crops. Three species of capsid have been seen in the vicinity of infested celery crops: common green capsid, European tarnished plant bug and what appeared to be *Orthops campestris,* which does not have a common name. Crop invasion by capsids is unpredictable and relatively little is known about their biology, particularly the biology of *O. campestris*, 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.

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

Capsid bugs damage fruit and vegetable crops in the UK and are also pests of certain species of ornamental plant. Several species of capsid 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 HDC commissioned a project (PC123 - Control of capsid bugs within IPM programmes in protected crops) aimed at improving the knowledge of the behaviour of plant feeding capsids 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 HDC have funded several other projects on the management of capsids 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 capsid species 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 capsids, 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 HDC 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 capsid damage in celery (Figure 1) suggest that the status of capsids as pests of this crop is increasing, particularly in organic crops (David Norman, personal communication). Three species of capsid 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 this summer suggest that *O. campestris* may be the cause of most of the damage. Crop invasion by capsids is unpredictable and relatively little is known about their biology, particularly the biology of *O. campestris*, 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 capsid bugs.

Current control of capsids 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 capsids 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 capsids 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 capsid bugs that can infest celery crops, identify the key pest species, and identify and evaluate approaches to control.

(i) Project objective(s):

1. Develop a clearer understanding of the identity and life cycles of the key species of capsid 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 capsid 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 capsid 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 capsid populations.
6. Identify promising approaches that could be investigated in a subsequent project.

Only objectives 1, 2 and 4 will be covered in this report on the first year of the project.

Experimental

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

Materials and methods

Sampling crops and field margins

Sampling of field margins was carried out at 4 locations on G's farms where celery was grown from 1 April 2015 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 1.1. 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 capsid was caught it was placed in a pot with alcohol and labelled with location and date.

Table 1.1. Sites where field margins sampled in 2015

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

Crop sampling

Crop sampling was carried out regularly in organic celery crops once activity started, for around 4-6 weeks per site whilst the crop was at the right growth stage to be attractive to capsids (Table 1.2). Five plants per week from an uncovered area were carefully pulled up and shaken into an insect proof bag and capsids were collected. The occasional capsid found in conventional crop walking was also captured and saved in pots with alcohol.

Table 1.2. Crop sampling sites in 2015

Field	Farm	Town	OS
Severals	Dimmock Cotes	Stretham	TL 53437 73143
College Field	Hainey Farm	Barway	TL 54389 76196
Mortlocks	Hainey Farm	Barway	TL 54692 74373
21&8	Hainey Farm	Barway	TL 54057 74275

Further samples were collected from field margins surrounding organic crops by Ela Witkowska from G’s. 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 and field margins

The most abundant species of capsid was identified as *Orthops campestris* (Anon. 2016) and this identification was verified by Joseph Botting an expert on plant feeding bugs (British Bugs http://www.britishbugs.org.uk/heteroptera/Miridae/orthops_campestris.html). Figures 1.1 and 1.2 show *O. campestris* adults from and in the field margins at G's.

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

Figure 1.2 Adult *Orthops campestris* adult on umbel.

Once the identity of *O. campestris* had been confirmed, the samples collected in alcohol were identified and Figure 1.3 shows the proportions of adult *O. campestris*, common green capsid (*Lygus pabulinus*), tarnished plant bug (*Lygus rugulipennis*) and unidentified nymphs in samples from the field margins and from the crop. Only *O. campestris* adults were found in the crop samples and this was true also for organic celery crops (E. Witkowska, personal communication). A large proportion of the capsids 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.

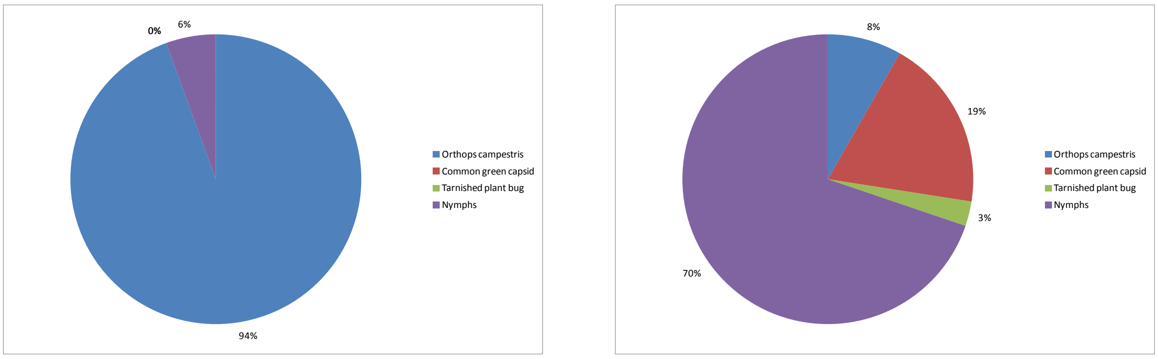

Figure 1.3 Proportions of adult *O. campestris*, common green capsid (*Lygus pabulinus*), tarnished plant bug (*Lygus rugulipennis*) and unidentified nymphs in samples from the celery crop (left) and field margins (right).

Figures 1.4–1.8 show the numbers of adults of each species captured versus date for the samples from the field margins (all species) and the celery crop (*O. campestris* only). Adult *O. campestris* were found from June to September.

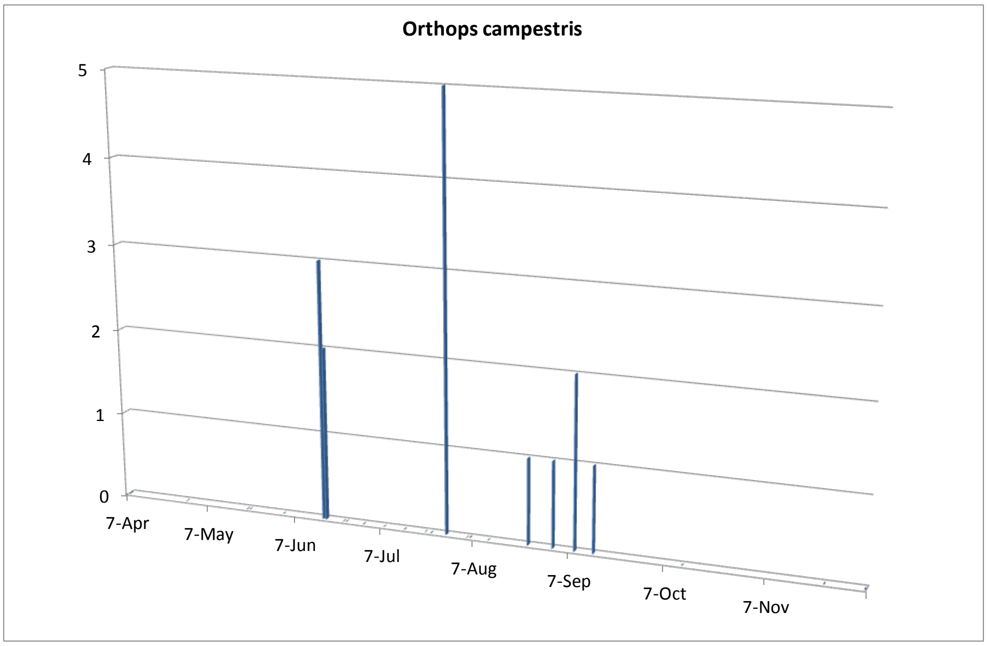

Figure 1.4 Numbers of adult *O. campestris* in samples from the field margins.

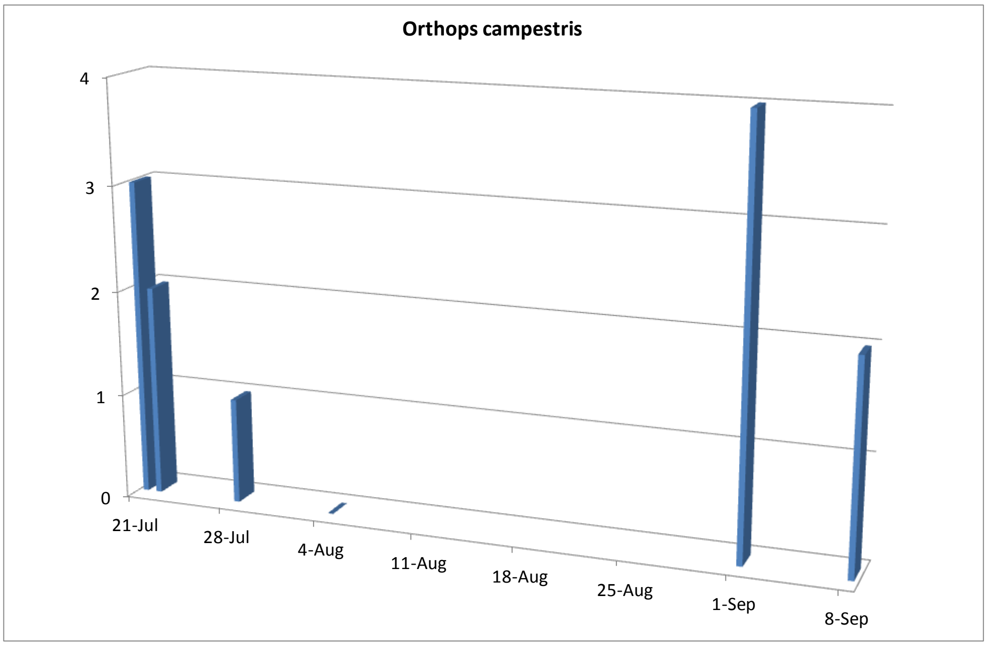

Figure 1.5 Numbers of adult *O. campestris* in samples from the celery crop.

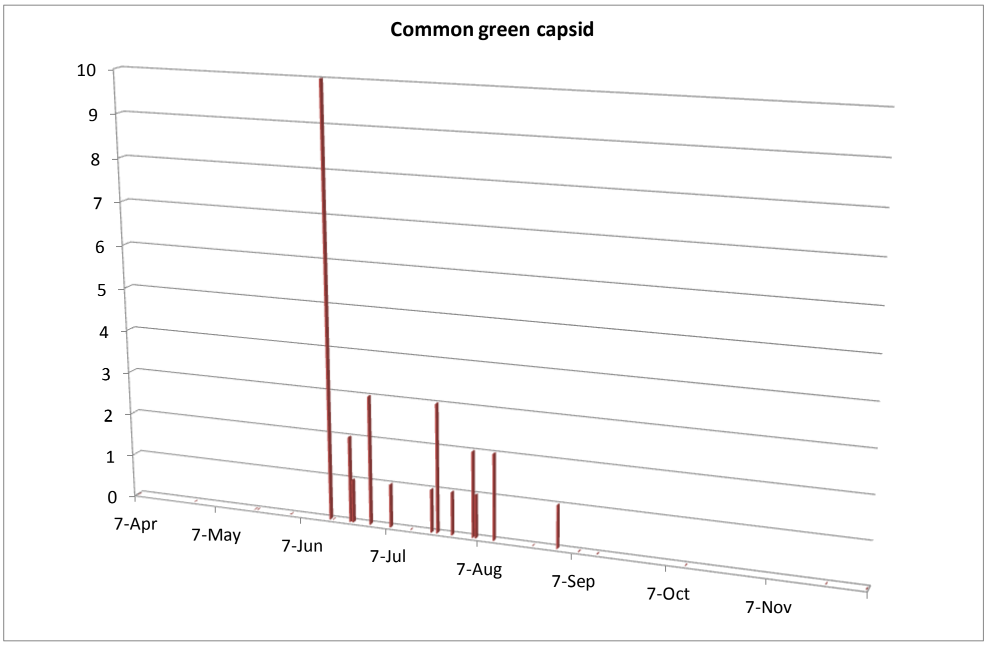

Figure 1.7 Numbers of adult common green capsid in samples from the field margins.

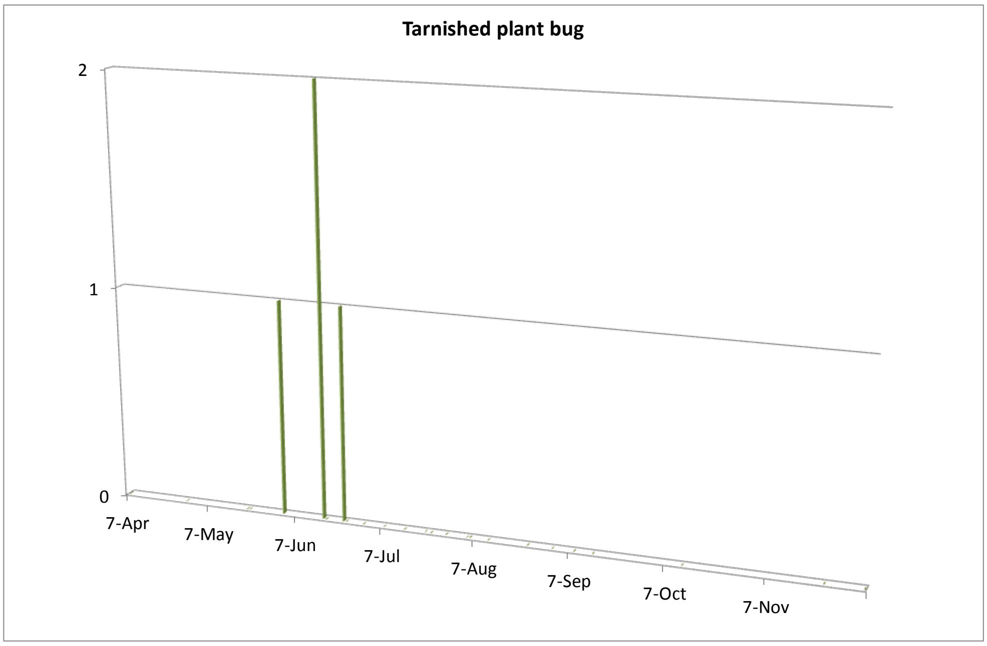

Figure 1.8 Numbers of adult tarnished plant bug in samples from the field margins.

Figure 1.9 summarises 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.

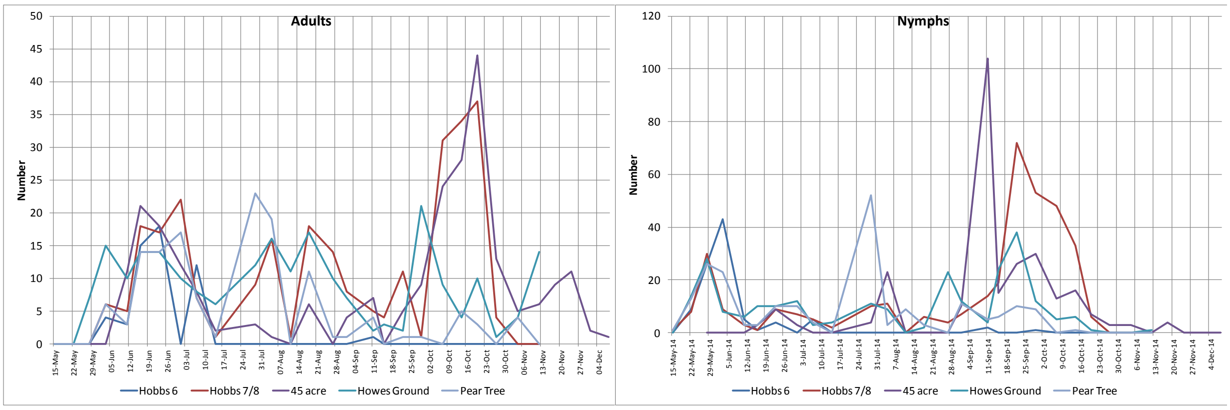

Figure 1.9. Numbers of adults (*O. campestris)* and nymphs (identification not verified) in samples from the vegetation surrounding organic crops of celery at G's in 2014 (data provided by E. Witkowska).

Similar data are shown for 2015 in Figure 1.10. 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.

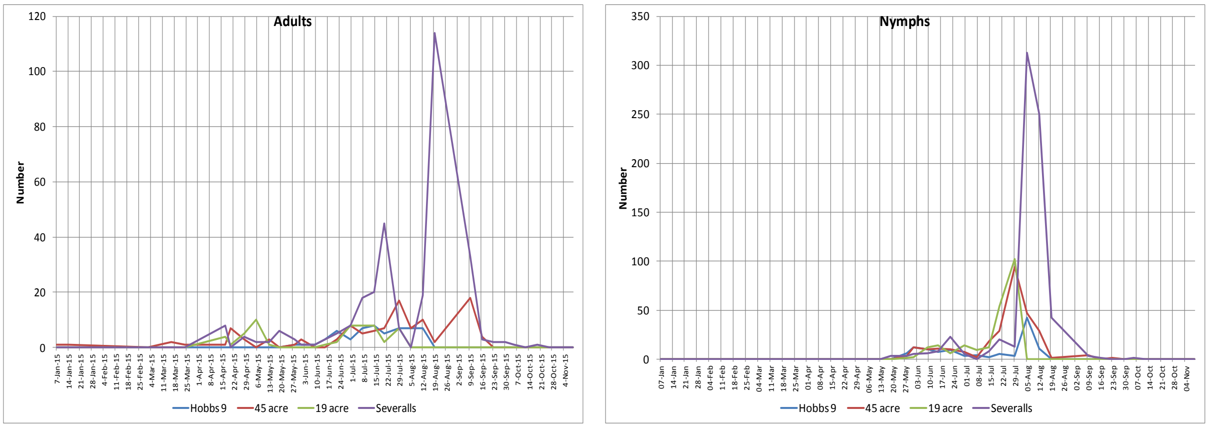

Figure 1.10 Numbers of adults (*O. campestris)* and nymphs (identification not verified) in samples from the vegetation surrounding organic crops of celery at G's in 2015 (data provided by E. Witkowska).

Figure 1.11 compares the activity of adults and nymphs in the two years and Figure 1.12 and Figure 1.13 show data on adults and nymphs respectively in 3 locations that were sampled more or less continuously during the main sampling period. All of the data suggest that there may be 3 'peaks' of nymphs in 2014 and 2 in 2015.

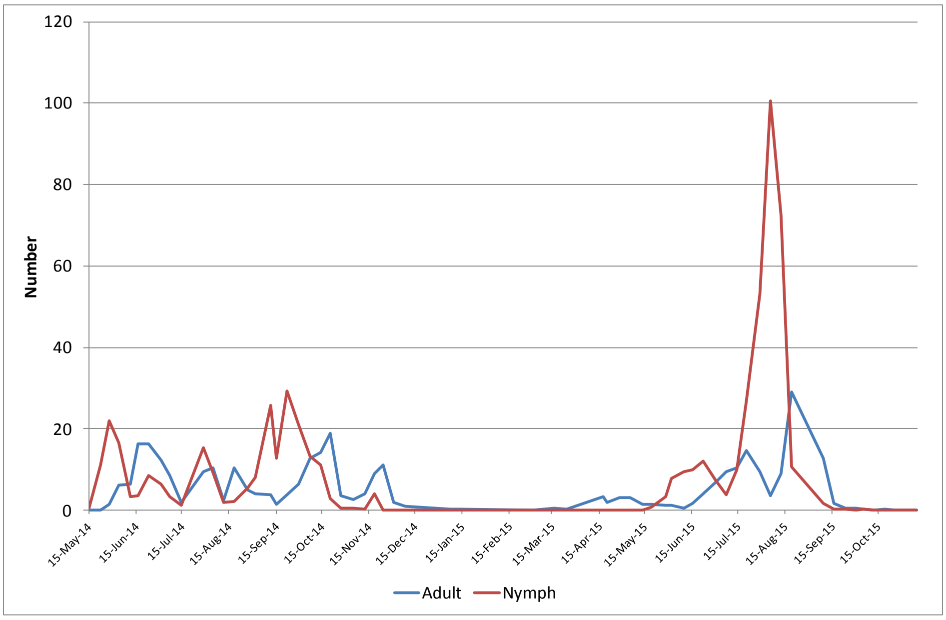

Figure 1.11 Numbers of adults (*O. campestris)* and nymphs (identification not verified) in samples from the vegetation surrounding organic crops of celery at G's in 2014 and 2015

(data provided by E. Witkowska).

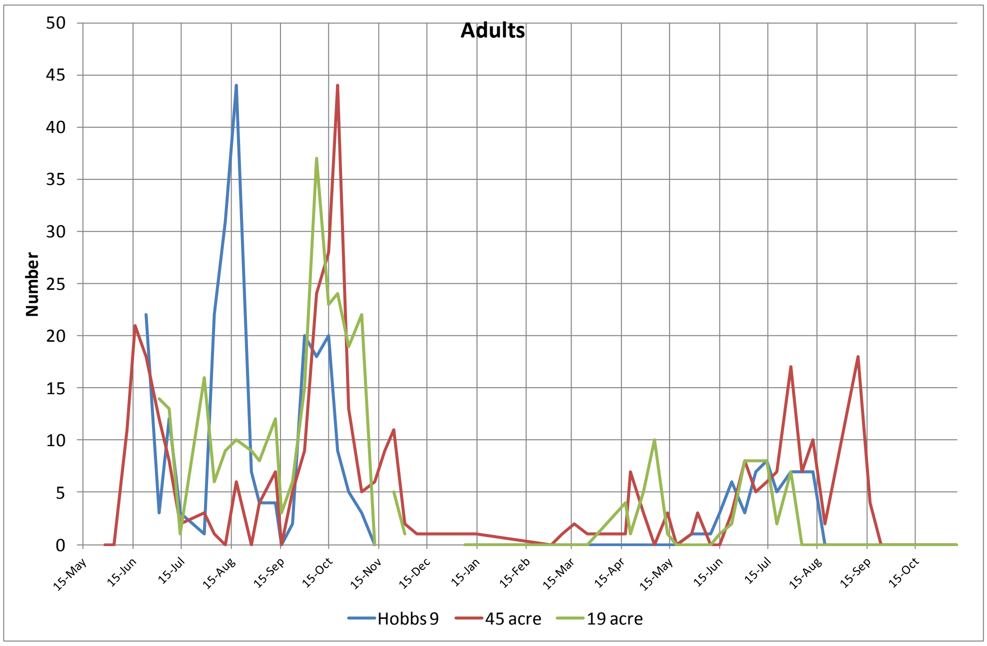

Figure 1.12 Numbers of adults (*O. campestris)* in samples from the vegetation surrounding 3 organic crops of celery at G's in 2015 (data provided by E. Witkowska).

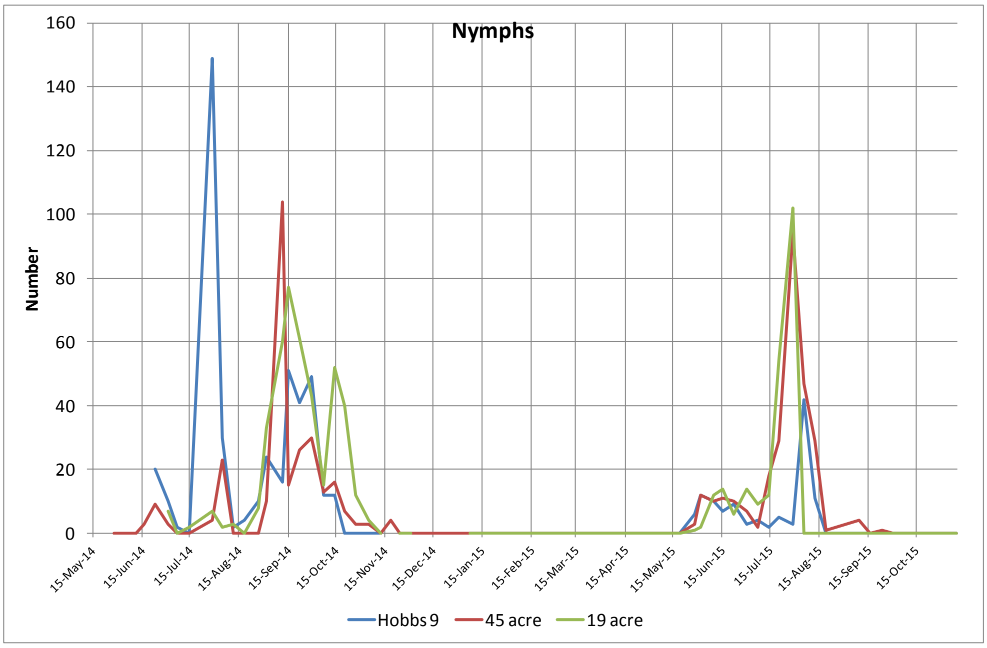

Figure 1.13 Numbers of nymphs (identification not verified) in samples from the vegetation surrounding 3 organic crops of celery at G's in 2015 (data provided by E. Witkowska).

In the absence of information about a suitable threshold temperature for development of *O. campestris*, accumulated day-degrees above a threshold of 6°C were estimated using weather data from the Norfolk site used for the AHDB Pest Bulletin. Figure 1.14 shows accumulated day-degrees from 1 January each year in 2014 and 2015. These data indicate that 2014 was warmer overall than 2015 and the ‘difference’ was about 2 weeks.

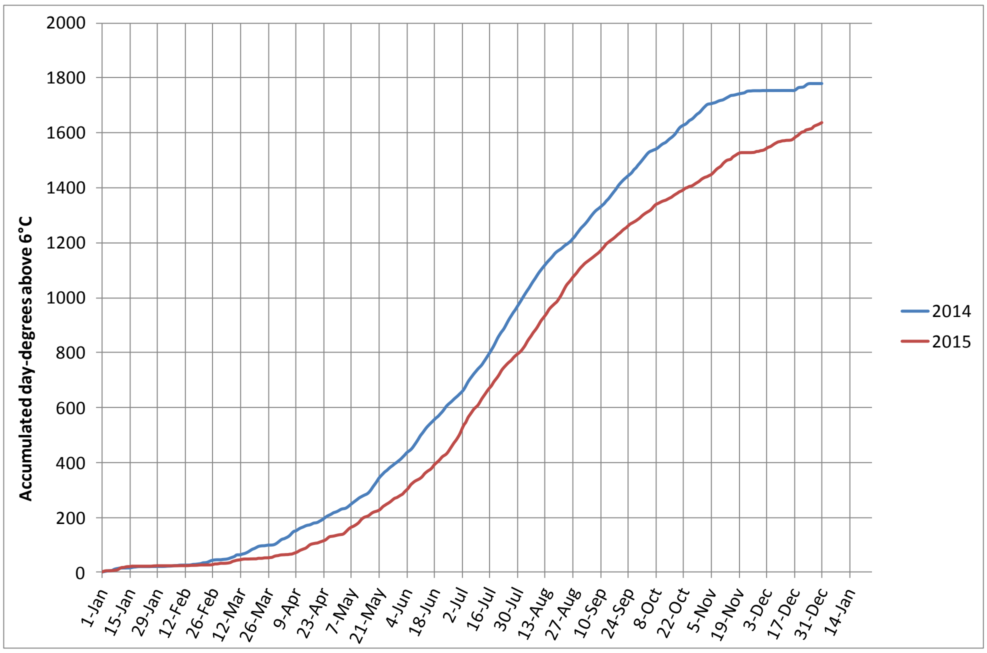

Figure 1.14 Accumulated day-degrees from 1 January each year in 2014 and 2015 above a base of 6°C.

Crop damage

Damage was seen particularly in the crops of organic celery (Figures 1.15 – 1.18).

Figure 1.15. Damage to organic celery by capsids.

Figure 1.16. Damage to organic celery by capsids.

Figure 1.17. Capsid nymph on organic celery plant.

Figure 1.18. Capsid nymph on organic celery plant.

Crop walking records of capsid presence and damage in G's crops in Norfolk and Cambridgeshire in 2015 are shown in Table 1.3. Damage occurred between early July and the end of August.

Table 1.3. Records of capsid damage/activity in crops

Week No.	**Week Beginning**	**Cambridgeshire farms**	**Norfolk farms**
10-27	2 Mar – 29 Jun	0	0
28	6 Jul	First capsid and damage seen in organic crops	0
29	13 Jul		First capsid damage recorded Rosedene farm conventional crop

Week No.	Week Beginning	Cambridgeshire farms	Norfolk farms
30	20 Jul	More capsid damage found 21/8, N16, N20, conventional crop	More capsid damage found
31	27 Jul	Increasing damage	Increasing damage
32	3 Aug	Less capsids found in crop	
33	10 Aug		Less capsid found in crop
34	17 Aug		
35	24 Aug		
36	31 Aug	No capsid activity in conventional crops Still plenty found in organics	No capsid activity or damage seen
37	7 Sep	Organic crops only	None found
38	14 Sep	Organic crops only	0

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 capsids were collected in early August 2015 by shaking the flower heads of wild apiaceous host plants into Bugdorm® cages (30 x 30 x 30 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 (*Orthops 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 the *O. campestris* were moved to new cages by selectively removing them with a pooter.

The behaviour of the caged *O. campestris* was observed over time. At any moment a proportion of the adult *O. campestris* were on the roof 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 roof of the cage at any particular time during the day. It was impossible to count all the *O. campestris* in any cage so this was a relative estimate. The photoperiod in the controlled environment room was 12L:12D initially (lights on at 5 am) and observations were made under these conditions (records made 3-17 December), it was then altered to 16L:8D (lights on at 5 am) to see how this affected the periodicity of activity (records made 18-28 January).

Results

The adult *O. campestris* 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.

The numbers of *O. campestris* on the roofs 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 roofs at 12h and they were most numerous at 14h under a 16L:8D photoperiod. The decrease in maximum numbers between December and January was due to increased mortality.

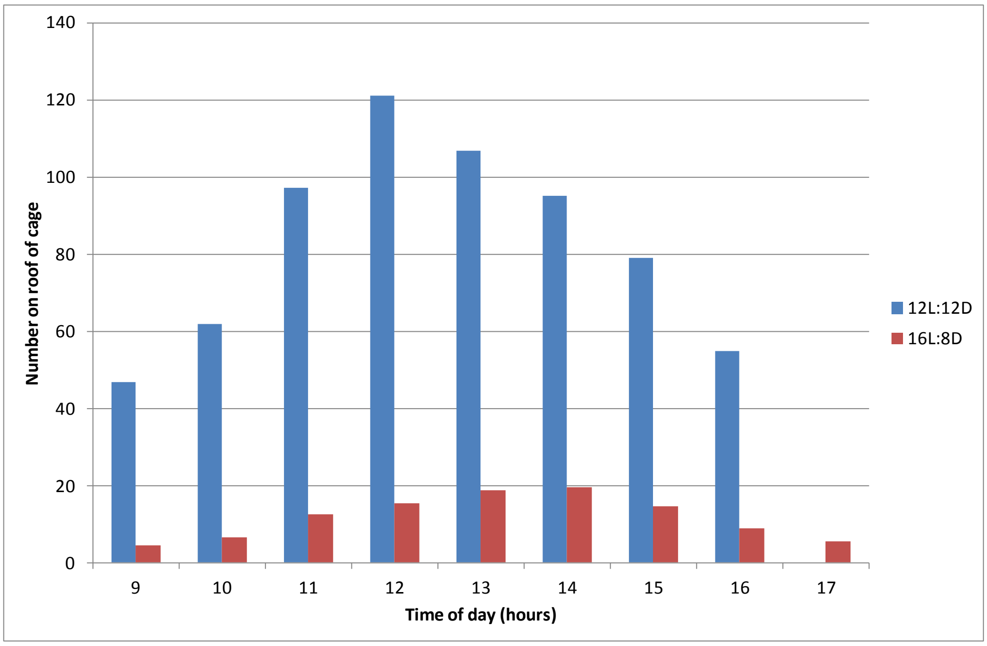

Figure 2.1 Number of *O. campestris* on the roofs of cages in a controlled environment room at 15°C and 12L:12D photoperiod or a 16L:8D photoperiod.

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

Preparations were made to undertake a small field trial at G's in one of the conventional celery crops in 2015. 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 treatments are shown in Table 4.1.

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	Experimental			400
4	Hallmark zeon	lambda-cyhalothrin	50	400
5	Experimental			400
6	Experimental			400
7	Experimental			400
8	Untreated			400

Unfortunately an infestation of sufficient size to collect robust data did not occur. Approved insecticides are lambda-cyhalothrin, pymetrozine, spinosad and Majestik (maltodextrin). Pirimicarb has been Approved for aphid control on celery but will no longer be available.

The same approach will be taken in 2016. However, it seems that it will be more productive to undertake small scale laboratory tests with *O. campestris* collected from the field. It is certainly possible to maintain adults in good condition for a long period of time, which means that these are suitable candidates for efficacy trials with both insecticides and bioinsecticides (at Warwick Crop Centre) and predators (Stockbridge Technology Centre).

Stockbridge Technology Centre has drawn up a protocol for small-scale tests of biocontrol agents. The only product specifically for control of capsids is Tigranem (Koppert - unspecified *Steinernema* nematode sp.). Generalist predators, such as ladybirds and lacewings, are likely to be effective. Other natural enemies may not be effective against adults, but may be useful against nymphs and eggs. Potential test organisms that are available commercially are *Tigranem* (Koppert)*, Macrolophus pygmaeus, Coccinella septempunctata, Adalia bipunctata and Chrysoperla rufilabris.*

Discussion

The 'British Bugs' web site (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 0.7mm long and found in developing carrot seeds.

The data obtained to date from celery crops and field margins confirm that *O. campestris* overwinters as an adult (sampling in 2014 began too late to detect the first period of adult activity). In 2015, where monitoring started in January, adults became more active in mid-April and the first nymphs were found in mid-May. These nymphs would be part-way through development. It seems unlikely that this species completes a single generation and the data from 2015 suggest that there are two generations – as indicated for populations in the Netherlands (Van Turnhout and van der Laan, 1958). The data from 2014 indicate that there might possibly be 3 generations.

There was a clear pattern in the activity of *O. campestris* adults maintained in the laboratory. Under a 12L:12D photoperiod the adults were most numerous on the cage roofs at 12h and they were most numerous at 14h under a 16L:8D photoperiod. In both cases the lights were turned on at 5h.

All of the host plants of *O. campestris* mentioned in the literature are members of the Apiaceae. If this is the case then there may be opportunities to reduce infestations of *O. campestris* by managing apiaceous weeds in the vicinity of the crop. This is in contrast to common green capsid and European tarnished plant bug which have a wide range of host species (Blommers *et al*.,1997; Holopainen, & Varis, 1991; Petherbridge & Thorpe, 1928), which might make selective management of vegetation very difficult.

Large numbers of capsids were captured in August and kept in a controlled environment room at 15°C at Warwick Crop Centre. The nymphs appeared to die very quickly but the adults survived until early January. There was no evidence that they produced young during this period. The simplest explanation is that these adults were in reproductive diapause and that they did not receive the environmental cues to complete diapause and begin to reproduce. Further culturing conditions will be explored in 2016 to determine whether these enable the adults to reproduce. The fact that the adults survived so long means that they will be good candidates for pesticide and biopesticide efficacy trials. However it will be important also to test nymphs. It is likely that the eggs will be inaccessible to control with either insecticides or biocontrol agents.

Conclusions

Key conclusions are:

- The pest species causing damage to celery crops is *O. campestris.*
- Presence of *O. campestris* is strongly associated with apiaceous host plants.
- *Orthops campestris* overwinters as an adult in field margins and it is most likely that it completes 2 generations per year.

Work plan for 2016

It is clear that in 2016 further work must focus on the biology and control of *O. campestris*. Key activities will be to:

- Sample the spatial distribution of *O. campestris* on field margins to determine their association with wild host plants, especially Apiaceae.
- Relate the abundance of *O. campestris* in field margins to damage in nearby celery crops.
- Monitor the phenology of *O. campestris* in crops of celery and in field margins.
- Collect *O. campestris* adults and nymphs as soon as they appear and culture at high temperatures/long day lengths with apiaceous umbels and other sources of food. Determine generation times under these conditions.
- Collect *O. campestris* adults and nymphs to undertake laboratory tests using approved and novel insecticides, bioinsecticides and biocontrol agents.
- Plan to undertake a field trial on Approved insecticides if the infestation is sufficiently large.

Knowledge and Technology Transfer

There has been no activity to date.

References

Anon. (2016). *Orthops campestris* - British Bugs website. http://www.britishbugs.org.uk/heteroptera/Miridae/orthops_campestris.html (accessed March 2016).

Blommers, L. H. M., Vaal, F. W. N. M. and Helsen, H. H. M. (1997). Life history, seasonal adaptations and monitoring of common green capsid *Lygocoris pabulinus* (L.) (Hem., Miridae). Journal of Applied Entomology, 121, 389-398.

Brittain, W. H. (1919). Notes on *Lygus campestris*, L., in Nova Scotia. Proceedings of the Entomological Society of Nova Scotia, 1918-1919, February 76-81.

Frohlich, G. (1960). Life histories and control of *Lygus campestris* and *L. kalmi* on fennel. Zur Lebensweise und Bekämpfung der an Fenchel (Foeniculum vulgare Miller) schädigenden Blindwanzen *Lygus campestris* L. und *L. kalmi* L. Pharmazie 15, 334-41.

Handford, R.H. (1949). *Lygus campestris* (L.): A New Pest of Carrot Seed Crops. The Canadian Entomologist, 81, 123-126

Holopainen, J.K & Varis, A-L. (1991). Host plants of the European tarnished plant bug *Lygus rugulipennis* Poppius (Het., Miridae). Journal of Applied Entomology. 111, 484–498.

Petherbridge, F. R. And Thorpe, W. H. (1928). The common green capsid bug (*Lygus pabulinus*). Annals of Applied Biology, 15, 446-472.

Van Turnhout., H.M.Th. and van der Laan, P.A. (1958). Control of *Lygus campestris* on carrot seed crops in North Holland. T. Pl. ziekten 64, 301-306.

Wheeler, A.G. (2001). Biology of the plant bugs. Cornell University Press.507 pp.

Whitcomb, W.D. (1953). The Biology and Control of *Lygus Campestris* L. on Celery *Issue 473 of Bulletin (Massachusetts Agricultural Experiment Station)*.

