Project title:	Lettuce and baby leaf salads: Investigation into control measures for Silver Y moth and caterpillars
Project number:	FV 440
Project leader:	Rosemary Collier, University of Warwick
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Location of project:	Warwick Crop Centre and commercial growers
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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.

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GROWER SUMMARY

Headlines

- Trials have indicated several insecticides with efficacy against silver Y moth and diamond-back moth, some of which are novel products.
- A novel ‘remote’ monitoring system which uses a small camera located inside a pheromone trap to record moth captures daily showed promise as a method for monitoring the arrival of migrant pest moths of salad and vegetable crops, but requires further development to increase catch sizes.
- Use of citizen science data together with information on wind drection may enable provision of short-term forecasts for pests arriving into the UK from mainland Europe and provide the possibility of a warning network.

Background

Damage caused by the larvae of the silver Y moth and other species of moth can result in unacceptable leaf damage in outdoor baby leaf and lettuce crops, where there is zero tolerance for either the presence of, or visible damage from, these pests. Loss of active ingredients has left the industry with a fairly small range of insecticides, some of which have limited efficacy, and all have long harvest intervals. This is resulting in poor control of these pests in UK crops. The overall aim of Project FV 440 is to provide growers of lettuce and baby leaf salad crops with the tools (decision-support and control methods) to improve overall control of silver Y moth and other pest caterpillars.

Summary

Evaluation of insecticides and bioinsecticides

Trials were undertaken with silver Y moth and diamond-back moth. Although no trials were undertaken with turnip moth, some of the products tested may be effective against this species.

Silver Y moth: The aim was to complete four field trials on either whole head lettuce (2 trials) or baby leaf (2 trials). Treatments were chosen with regard to likely efficacy and potential for registration. All trials were infested artificially with eggs/larvae from moths captured with light traps and all were completed successfully (Tables A & B).

Table A. Effect of insecticide and bioinsecticide treatments on silver Y moth larvae in whole head lettuce

Product	Active	Mean numbers of live silver Y moth larvae 4 (2015) and 6-8 (2016) days after treatment compared with untreated control	
		2015	2016
	Azadirachtin	Ns	Ns
HDCI 089	Bioinsecticide	Ns	Ns
HDCI 090	Insecticide	***	*
HDCI 100	Bioinsecticide	Ns	Ns
HDCI 102	Insecticide	-	Ns
HDCI 103	Insecticide	-	*
Lepinox Plus	*Bacillus thuringiensis*	Ns	Ns

Table B. Effect of insecticide and bioinsecticide treatments on silver Y moth larvae in baby leaf lettuce

Product	Active	% mortality of silver Y moth larvae 2 (2015) and 3 (2016) days after treatment compared with untreated control	
		2015	2016
Warrior (2015), Ninja (2016)	Lambda cyhalothrin	***	***
	Cyazypyr	***	***
	Emamectin benzoate	Ns	Ns
	Indoxacarb	***	***
HDCI 091	Insecticide	***	Ns
Coragen [Previously coded as HDCI 096]	Chlorantraniliprole [Previously coded as HDCI 096]	***	Ns

- Ns Larval mortality not significantly higher than untreated control
- *** Larval mortality significantly higher than untreated control ($p<0.001$)
- * Larval mortality significantly higher than untreated control ($p<0.05$)

For the trials on whole head lettuce (Table A), in 2015 the insecticide HDCI 090 was the most effective treatment and the only treatment which significantly decreased numbers of live larvae compared with the untreated control. In 2016, plants were inoculated with eggs or larvae before spray treatments were applied. The pre-planting insecticide treatment (HDCI 103) killed all larvae and also significantly reduced the number of feeding holes on leaves. HDCI 090 also reduced larval numbers compared with the untreated control but the level of statistical significance was lower than in 2015, probably because of the small numbers of larvae recovered overall. For the trials on baby leaf lettuce (Table B), in 2015, 2 days and 9-10 days after spraying, all treatments except emamectin benzoate led to lower numbers of larvae versus the control. In 2016, 3 days after spray treatment, lambda-cyhalothrin, indoxacarb and cyazypyr had reduced numbers of larvae compared with the control and emamectin benzoate. After 10 days, all treatments except emamectin benzoate had reduced numbers of larvae compared with the control.

Diamond-back moth: In 2016 a laboratory trial on Brussels sprout plants used diamond-back moths from a population maintained at Warwick Crop Centre for a number of years. Three days after spraying all treatments had reduced the percentage of live larvae compared with the untreated control and continued to do so after 6 and 10 days. Tracer (spinosad), cyazypyr, Coragen (chlorantraniliprole) and the bioinsecticide Lepinox Plus (*Bacillus thuringiensis*) were the most effective, treatments with 100% mortality after 3 days. In 2016-7 a glasshouse trial on Brussels sprout plants used diamond-back moths collected from the field in summer 2016 following a large migration of moths and cultured subsequently. It was considered likely that these insects were resistant to pyrethroid insecticides (Steve Foster, personal communication) and this was confirmed in the trial (Figure A) as Hallmark (lambda-cyhalothrin) was ineffective. Three days after spraying Tracer, cyazypyr, azadirachtin, Coragen and Lepinox Plus had reduced the percentage live larvae compared with the untreated control.

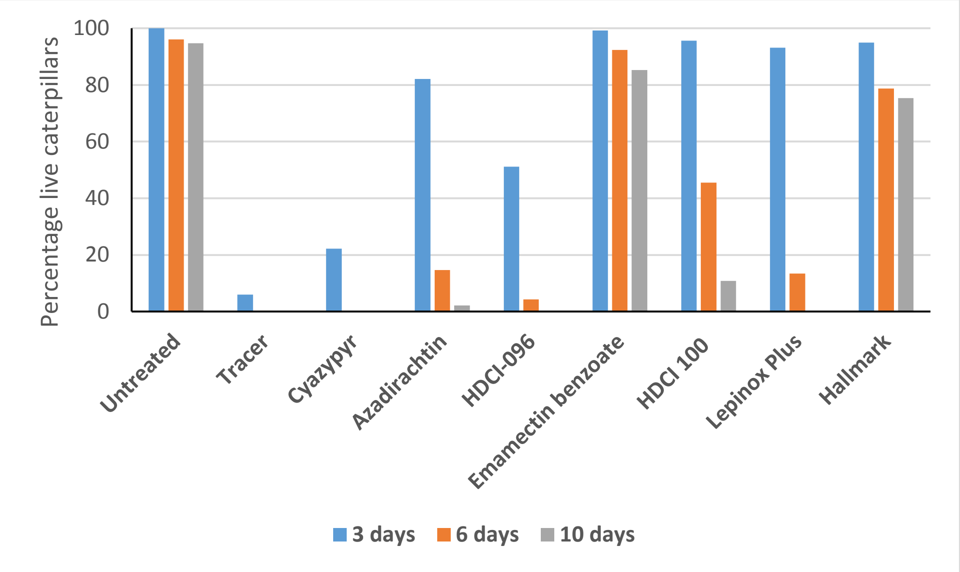


Figure A. Effect of insecticide / bioinsecticide treatments on the mean percentage live diamond-back moth larvae 3, 6 and 10 days after spraying, glasshouse trial on Brussels sprout plants, 2016-7. [HDCI 096 = Coragen (chlorantraniliprole)]

Monitoring and forecasting pest moths to support decision-making

Historical data: Captures of silver Y moth made by the network of light traps run by the Rothamsted Insect Survey over the last 50 years showed that there is considerable variation in overall abundance from year to year; confirmed by the other sets of historical data. Data on diamond-back moth highlighted the very large numbers which migrated into the UK in 2016 compared with other recent years. Monitoring data for 1996 were also available; this was probably the most recent occasion, prior to 2016, when very high numbers of diamond-back moths occurred. Data on turnip moth confirmed that there are two generations per year and that the timing of these generations varies from year to year.

Monitoring pest moths in 2015-16: A network of pheromone traps was established to monitor pest moths. The traps were supplied by Trapview (www.trapview.com) and managed by Colin Carter of Landseer. Traps were set up in May-June 2015 and 2016 and consisted of 18 traps for silver Y moth, 10 traps for diamond-back moth and 2 traps for turnip moth. Traps were hosted by growers of salad and Brassica crops. Each trap contained a pheromone lure for the appropriate species, a sticky base to capture the moths and a small camera which photographed the sticky base once each day. The camera was powered by a solar cell. The image was downloaded onto the website managed by Trapview and the images of the captures by all the traps were visible to all trap hosts.

Figure B. Trapview pheromone trap

In general, the Trapview traps were less effective than 'ordinary traps' (Funnel traps for silver Y moth and turnip moth and Delta traps for diamond-back moth). Some modifications were made to the Trapview traps in 2016 and, in particular, a trap that was modified to incorporate a Funnel trap was more effective in capturing silver Y moths. There were a few other small technical problems with the Trapview traps that need addressing but, overall, the network functioned well and all trap hosts were able to view all the traps remotely. All of the traps indicated periods when moths were more abundant but there was considerable variation within a region/locality in the numbers of moths captured. There is no evidence that moths were captured earlier at sites that were further south or further east, for example. Neither 2015 nor 2016 were years when silver Y moth caused major problems in salad crops. Whilst infestations usually followed periods of relatively high moth abundance, there seems to be little scope to develop a threshold based on the numbers of moths trapped as the small number of sets of data available did not suggest that there would be a consistent relationship. Thus moth trap captures can only be used to warn of/highlight periods when significant egg-laying is likely to occur. In the case of this pest there is likely to be an interval between egg-laying and the start of feeding damage by larvae. Using the day-degree sum for the development of silver Y moth eggs (approximately 60 day-degrees above 7.7°C (estimated from published data)) indicated that, for example, eggs laid on 14 June 2015 in Kent would have hatched approximately 9 days later. This type of information might be included in the AHDB Pest Bulletin. A small study by Rothamsted Research on the origin of migrant silver Y moths indicated that in 2015 the major source of moths, on the occasions when possible flight paths were tracked, was northern France.

It seems likely that migrant diamond-back moths are sexually active and able to lay eggs as soon as they arrive. After a very marked influx of moths at the end of May 2016 male moths were soon detected in pheromone traps, although not in the very high numbers that would have been expected from such a large infestation. There was a perception by some growers that in 2016 there was a delay between moth arrival and egg-laying/development of the immature stages. However, the timing of what seems to be a subsequent (second) generation (Figure C) ties in closely with the day-degree sum for development of eggs, larvae and pupae estimated from published data.

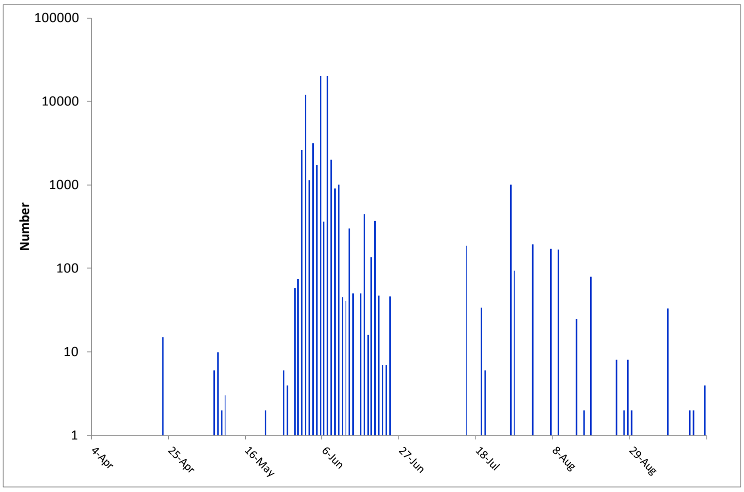


Figure C. The numbers of diamond-back moths per day reported on Twitter in 2016.

The project has highlighted the value of information about migrant moths available on web sites and social media (Figure C). This was particularly useful in a second small study done by Rothamsted Research on the source of the large influx of diamond-back moths in 2016. Data from web sites on the continent were used to indicate where infestations of diamond-back moth had been building, which included Scandinavia and Belgium/the Netherlands. To test whether it was possible to identify the source location for the initial incursion of diamond-back moth into the UK on 1 June, the Rothamsted team used the HYSPLIT trajectory model to undertake back-trajectory analysis. The results suggested that the initial incursion into the UK originated from the Norwegian and Danish coastlines. This is somewhat surprising, given that there were significant numbers of diamond-back moths throughout the low countries during this whole period, following a build-up of populations there from mid-May onwards, and the populations there would have a much shorter distance to cover in order to arrive at the UK coastline. However, wind directions were not favourable for this to happen at that time. Use of information on moth sightings in mainland Europe may be valuable to UK growers and this is being explored with AHDB funding in 2017 by providing growers with a web page summarising sightings of silver Y moth and diamond-back moth in northern Europe.

Financial Benefits

The benefits of the project will be improved quality of crops marketed and fewer crop losses and rejections. The scale of potential losses is exemplified by the impact of the diamond-back moth incursion in 2016 and reported at the AHDB Workshop on 24th January https://horticulture.ahdb.org.uk/diamondback-moth.

Action Points

- Growers should make themselves aware of the likelihood of egg-laying by pest moths of salad and Brassica crops, either through monitoring themselves or by being part of an information network.
- Growers should also make themselves aware of the relative susceptibility of pest moths to the control methods available to them. In the case of diamond-back moth it is important to obtain as much information as possible about the resistance status of immigrant moths.

SCIENCE SECTION

Introduction

Damage caused by the Silver Y moth and other caterpillar species can result in unacceptable leaf damage in outdoor baby leaf and lettuce crops where there is zero tolerance for either the presence of, or visible damage from, these pests. Loss of active ingredients has left the industry with a fairly small range of insecticides, some of which have limited efficacy, and all have long harvest intervals. This is resulting in poor control of these pests in UK crops. There are potentially a number of damaging species including silver Y moth and turnip moth (cutworm) which have a range of hosts and also the brassica specialists such as diamond-back moth that may infest baby leaf crops.

Silver Y moth

Larvae of the silver Y moth (*Autographa gamma*) have a fairly wide range of host plants including beet, potato, maize, brassica, and legumes, but are particularly damaging to lettuce and related crops. The silver Y moth is a migrant species and infestations usually first arise as a result of immigration by moths in May and June.

The migration patterns of the silver Y moth have been studied in the UK in the context of increasing our understanding of insect migration activity (Chapman *et al.*, 2012). Spring migrants use fast-moving airstreams, 200–1,000 m above the ground, to travel 300 km northward per night to colonize temporary summer-breeding grounds in northern Europe, from their winter-breeding grounds in North Africa and the Middle East. Radar tracking was used to estimate the annual abundance of immigrating moths during the period 2000–2009. Three years (2000, 2003, and 2006) had high immigrant migrations in spring, corresponding to an estimated 225–240 million adult moths immigrating into the whole of the UK, whereas in the other 7 years the UK received roughly one-ninth that number (10–40 million immigrants). Other outbreak years in the last hundred years have included 1946 and 1996 (documented by the Dorset Moth Group and others).

In the autumn (August and September), silver Y moths return to their winter breeding grounds and Chapman *et al.* (2012) estimated that 80% of emigrants reach regions in the Mediterranean Basin suitable for winter breeding. They also estimated that summer breeding in the UK results in a four-fold increase in the abundance of the subsequent generation of adults, all of which emigrate southward in the autumn. As a result they concluded that the persistence of this species is dependent on summer breeding in high-latitude regions such as the UK, because there is insufficient fresh vegetation to support them in the Mediterranean Basin during the summer months. The information used in the paper by Chapman *et al.*

(2012) was obtained from the Rothamsted Insect Survey light trap network as well as by radar tracking.

Monitoring silver y moth

Moth enthusiasts usually monitor silver Y moths using light traps, whilst pheromone traps are more practical for use by growers. The pheromone traps use synthetic female sex pheromone to attract male moths and the assumption is made that the female moths are laying eggs on host plants at the time that the male moths are captured. The precise timing of the arrival of silver Y moth in spring/summer appears to vary from year to year, as does the overall pattern of trap captures (HDC Projects FV 163, FV 163a, FV 192, PC 132), although peaks in abundance, probably representing a new influx of immigrant moths, often occur at a similar time at locations within a region (FV 163a). Crops in the south and east seem to be most at risk from infestation. Within a locality, pheromone traps sited in different locations may catch different numbers of moths (D. Norman, personal communication), although in other cases catch sizes may be very similar (e.g. traps deployed in brassica crops in south Lincolnshire in 2000 (FV 163a)).

It is possible to find silver Y moth eggs and larvae on plants during crop walking. However, the eggs are small and laid singly, and can be hard to find. The small larvae are green and are often relatively inconspicuous on foliage. One of the biggest problems with silver Y moth larvae and lettuce is that once the larvae are a bit bigger they start “burrowing” into the lettuce heads and can often get 2-3 leaves into the head of an iceberg lettuce. This makes them difficult to spot by the harvesters and so can cause customer complaints /supermarket rejections.

Action thresholds

Attempts have been made to relate the numbers of silver Y moths captured in pheromone traps to the numbers of eggs/larvae found on plants. This has been done in the UK for peas (FV 192) and vegetable brassicas (FV 163a) respectively. For peas, it was estimated that a threshold catch was reached when the cumulative catch by the first pod stage (gs 204) exceeded 50 moths. For brassicas, the conclusion was that this was not a very ‘susceptible’ host crop because although moth numbers were often relatively high, none of the 50 site/generation combinations for which there was pheromone trap/larval count data had more than 1 larva per plant at the peak. In the case of vegetable brassicas this ‘relatively low’ level of infestation is unlikely to cause problems in most instances, whereas such a situation would be more problematic on lettuce and baby leaf crops.

Control

Control of silver Y moth with different insecticides was not investigated in the previous HDC projects FV 192, PC 132 and FV 163a. Insecticides and bioinsecticides (two *Bt* products) were evaluated against some pest species of larva in FV 163 but populations of silver Y moth larvae were too low for this species to be targeted.

In the more recent SCEPTRE project (CP 077), laboratory tests at Warwick Crop Centre in 2013 evaluated the efficacy of conventional insecticides and bioinsecticides against silver Y moth larvae. To obtain the larvae, female moths were captured in a light trap at Warwick Crop Centre and caged with lettuce plants in the Insect Rearing Unit so that they laid eggs which hatched subsequently producing larvae.

The three coded conventional insecticides tested in the SCEPTRE project showed excellent activity against silver Y moth when applied as foliar sprays (100% control) (Table 1.1). In a small unfunded trial, two coded conventional insecticides were applied as drench treatments to the peat blocks containing the lettuce plants and both provided 100% control, indicating systemic activity. There was evidence of some persistence with both methods of application with all the products tested. Four coded bioinsecticides showed varying levels of control of silver Y moth larvae (Table 1.2).

Table 1.1. Data from SCEPTRE project on control of silver Y moth larvae with coded insecticides

SCEPTRE Code	Mean % larvae surviving		Mean number of feeding holes	
	Fresh residue	Aged residue (7 days)	Fresh residue	Aged residue (7 days)
Untreated	66	70	58.5	Plants dead
Cyazypyr (SI2013-50)	0	0	0.9	0.7
Spinosad (SI2013-140)	0	0	4.1	2.8
Emamectin benzoate (SI2013-48)	0	0	3.1	2.7

Other pest caterpillars of lettuce

Lettuce and related crops may also be infested by larvae of the turnip moth (*Agrotis segetum*) (cutworms) and occasionally by species of Tortrix moth. The turnip moth is a sporadic pest of lettuce. The name derives from the habit of the older larvae of feeding underground, damaging plant roots and stems, sometimes so badly that the plant topples.

The adult moths lay eggs on plants or on pieces of litter and debris in the soil, usually from the end of May or early June. These hatch in around 8-24 days, depending on temperature. The young larvae seek out and feed on the aerial parts of plants. In a further 10-20 days, again depending on temperature, the larvae go through their second moult, becoming “third instar” larvae. It is at this point that they adopt the cutworm habit, becoming subterranean and feeding on roots etc.

Unhatched turnip moth eggs and the older, subterranean cutworms are largely invulnerable to the effects of the weather and insecticides. The two early larva instars differ, however. If there is substantial rainfall (defined as 10 mm or more of rain falling in showers of moderate intensity over a 24-hour period) whilst these larvae are feeding above ground then this causes high mortality among them. They are also vulnerable to insecticides and irrigation whilst feeding on the foliage.

Table 1.2. Data from SCEPTRE project on control of silver Y moth larvae with coded bioinsecticides.

SCEPTRE Code	Mean % larvae surviving		Mean number of feeding holes	
	Angular	Back transformed means	Log	Back transformed means
Untreated	60.1	75.2	4.511	91.1
Nemasys-C (SI2013-94)	33.7	30.8	3.769	43.3
Azadirachtin (SI2013-130)	18.2	9.8	3.222	25.1
SI2013-51	37.7	37.5	3.831	46.1
Lepinox Plus (SI2013-68)	2.7	0.2	2.284	9.8
F value	20.31	75.2	17.95	
P –value	<0.001		<0.001	
Replicate no.	10		10	
d.f.	45		45	
s.e.d.	6.78		0.277	
l.s.d.	13.65		0.558	

The cutworm model is a computer program that uses weather data to predict the rate of development of turnip moth eggs and larvae. It also predicts the level of rain-induced mortality among the early-instar larvae. The cutworm model published by Bowden *et al* (1983) has been programmed into the MORPH decision-support software, and output from the model is also available as part of the AHDB Pest Bulletin. The model is run from when moths are first caught in pheromone traps. Once eggs are predicted to start to hatch then rainfall becomes important for the forecast. Rainfall events have major effects on the survival of young cutworms (from when they hatch until they reach the third instar (third larva stage – achieved through moults)) and this forms the basis of the forecast i.e. if a heavy rainfall event occurs when a particular cohort of young cutworms is present then it is assumed that they will be killed. For irrigated crops, the risk of cutworm damage is reduced as substantial irrigation has the same effect on cutworm survival as heavy rainfall.

Unlike silver Y moth, turnip moths overwinter in the UK and the timing of emergence is predictable using a simple day-degree forecast developed at Warwick Crop Centre. As with silver Y moth, turnip moths can be captured in light traps or with pheromone traps. There are no thresholds that relate numbers of moths captured in pheromone traps to infestation levels in crops. As with silver Y moth it is very hard to find eggs and small larvae whilst crop walking. Turnip moth larvae can be controlled with insecticides but once they become subterranean it is much harder to contact them. There has not been any recent work on the efficacy of insecticides and bioinsecticides against this pest.

Brassica specialists

Potentially this could cover several species but probably diamond-back moth (*Plutella xylostella*) and the small and large white butterflies (*Pieris brassicae, Pieris rapae*) present the greatest risk.

Diamond-back moth is similar to silver Y moth in that it does not overwinter very successfully in the UK and so major infestations early in the year are usually the result of migration across the Channel from continental Europe and further south. As with silver Y moth there have been particular outbreak years and often both species are abundant in a particular year (as in 1996).

Monitoring and action thresholds

Diamond-back moth can be monitored using pheromone traps whilst butterflies are monitored using yellow sticky traps or water traps. The use of traps to monitor larva pests of brassica crops was investigated in HDC projects FV 163 and 163a and the potential use of thresholds (both using pheromone traps and through crop walking) was explored in some detail in these projects. Pheromone traps can certainly be useful to indicate when large numbers of moths are entering crops, since female diamond-back moths will lay eggs at the same time that the traps are capturing male moths; and subsequent development is rapid so spray timing is critical. However, the relationship between the numbers of diamond-back moths captured in pheromone traps and the numbers of larvae found subsequently on plants in insecticide-free plots was not particularly consistent. Adult trapping data for the small white butterfly appeared to be extremely variable and is probably an unreliable indicator. Egg counts may provide a more reliable indication for this species. Some tentative guidelines were produced with regard to 'threshold' trap captures – but these will not be completely reliable.

Control

Control of brassica specialists was also investigated in FV 163, but the range of products available has changed considerably since then. Brassica caterpillars have been some of the targets for evaluation of coded insecticides and bioinsecticides in the recent SCEPTRE project and data for trials at Warwick Crop Centre in 2013 are shown in Figures 1.1 and 1.2. There are new insecticides and bioinsecticides that are potentially effective.

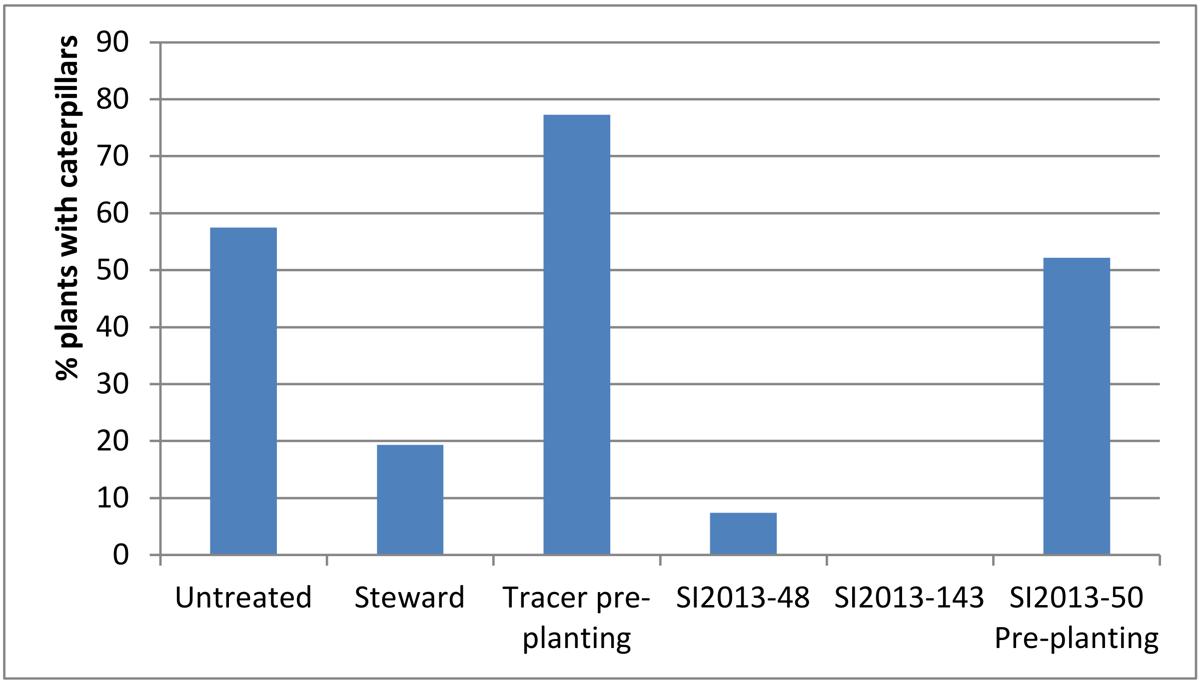


Figure 1.1. SCEPTRE project - larva control on Brussels sprout – insecticides - majority of insects were small white butterfly (*Pieris rapae*). N.B SI2013-BRU-48 is emamectin; SI2013-BRU-50 is cyazypyr.

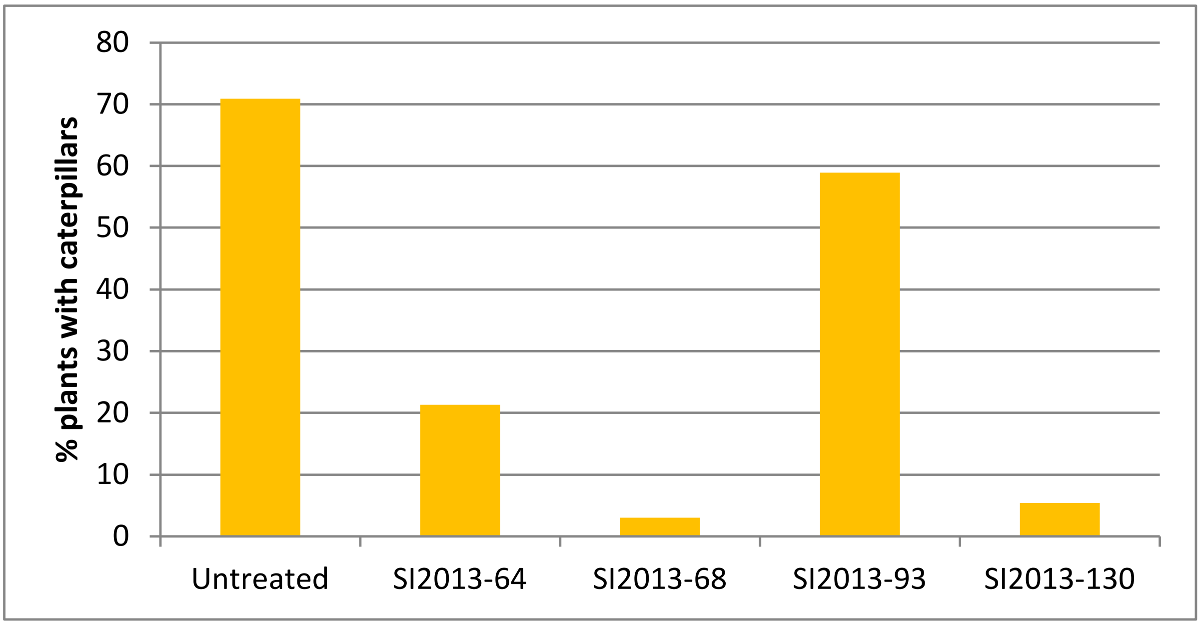


Figure 1.2. SCEPTRE project - larva control on Brussels sprout – bio-insecticides - majority of insects were small white butterfly (*Pieris rapae*). N.B SI2013-130 is Azadirachtin.

Novel methods of management/control – all species

A scan of published research using the search term *Autographa gamma* revealed 317 publications in the Web of Knowledge database. The majority of these are concerned with migration and pheromones. Other aspects that might be of interest in the context of this species were the response of moths to plant volatiles (when seeking nectar) and biological control with egg parasitoids.

For diamond-back moth in particular, a whole range of alternative methods of control have been investigated, including trap cropping, intercropping, biological control by releasing predators or parasitoids or by increasing numbers of natural enemies by enhancing the local environment. All of these approaches have limitations and most may not be appropriate for baby leaf crops. Exclusion methods (crop covers) may be effective, depending on pest species and how they are deployed, but are not always practical or economically viable for commercial crops.

Mass trapping using pheromone traps has been suggested as a possible approach to control of adult moths. However, before mass trapping of males with a female sex pheromone might be considered, it would be important to know exactly where and when the moths mate, as mass trapping at the egg-laying site might be ‘too late’ if the moths had mated before females arrived at the crop. ‘Confusion’ techniques using pheromones might be another approach to control, by releasing such large amounts of pheromone into the locality that male moths are unable to find female moths and mate with them. However, again this relies on ‘catching’ the moths before they have mated. ‘Lure and kill’ has been suggested as a further development of the use of pheromone traps but again it would be important to assess the ‘value’ of killing male moths as for mass trapping above. If an effective attractant for female moths could be identified, some of these approaches might be more successful. Other approaches that merit consideration would be more targeted use of irrigation to control cutworm larvae (and possibly silver Y moth larvae), although it would be worth assessing previous Danish research before planning future studies, and the performance of introduced or naturally-occurring natural enemies. However, level of control and speed of kill would be a consideration, especially close to harvest. This might also apply to bioinsecticides that do not kill very rapidly.

The focus of this project is on novel control agents (insecticides and bioinsecticides) and on the use of monitoring approaches to improve the identification of potential problems and aid decision-making with regard to treatment timing.

The objectives of the project are to:

1. Liaise with agrochemical companies and crop protection specialists to identify experimental conventional pesticides which may show efficacy in controlling larvae.
2. Consider the use of novel, approved or near market, biological control products which could be beneficial in reducing the risk of pesticide residues.
3. Gather accurate and detailed data during thorough assessments which will be statistically robust.
4. Carry out suitable, randomized and replicated, field trials to measure the efficacy of the chosen treatment regimes.
5. Develop a risk-based spray-decision-making system linked to trapping of moths and measure its efficacy, via field trials, against normal pest control practice.
6. Investigate other monitoring and control mechanisms which may be effective and make recommendations for how they might be developed through future research.
7. Engage and communicate with growers and other members of the industry.

Experimental

Trials to measure the efficacy of the chosen treatment regimes (Objectives 1,2,3,4)

Objective 1	Liaise with agrochemical companies and crop protection specialists to identify experimental conventional pesticides which may show efficacy
Objective 2	Consider the use of novel, approved or near market, biological control products which be beneficial in reducing the risk of pesticide residues.
Objective 3	Gather accurate and detailed data during the project by undertaking thorough assessments which will be statistically robust.
Objective 4	Carry out suitable, randomized and replicated, field trials to measure the efficacy of the chosen treatment regimes.

Collection of silver Y moths

Live adult silver Y moths were captured to produce eggs which were used to set up cultures in the laboratory/greenhouse to infest efficacy trials. Robinson light traps were purchased and set up in Cambridgeshire (run by ADAS, Boxworth) and at Wellesbourne and in Tysoe (Warwickshire) (5 traps in total).

Traps at Wellesbourne

The traps were run throughout the summer period in 2015 and 2016 and checked daily when operating (Figure 2.1). Although small numbers of moths were captured there were sufficient to start breeding cultures. All stages were kept in Bugdorm® cages (approximately 43 x 43 x 43 cm) in controlled environment rooms (18-20°C) in the Insect Rearing Unit. The female moths were allowed to lay eggs on potted lettuce plants and the larvae were also maintained on potted lettuce plants. The culture was allowed to go through several generations to build up numbers. When the larvae were crowded some of them died, either from a bacterial infection or due to a latent virus.

Figure 2.1. One of the Robinson light traps located at Warwick Crop Centre, Wellesbourne.

Traps at Boxworth

Light traps were used at ADAS Boxworth and in a private garden in Boxworth, Cambridgeshire to trap moths between 27 May and 16 July 2015 and over a similar period in 2016. Only low numbers of silver Y moths were trapped amongst the many other species including various hawk moths. Silver Y moths were trapped in the private garden which contained different flowering plants and trees and at various locations at ADAS Boxworth where there were flowering weeds e.g. dandelion and also flowering ornamental crops used in various trials. Silver Y moths were also caught with a net at ADAS Boxworth on flowering *Buddleia* and *Choisya*.

The first eggs from a silver Y female were collected on 16 July 2015 and a culture was established in a ventilated perspex insect rearing cage in a controlled temperature laboratory maintained at 21°C and with natural daylength at ADAS Boxworth. Flowers such as *Buddleia,* chrysanthemum, thistle, poppy, ragwort and nettle were supplied as a food source for the adult moths but these were then substituted with providing honey on a yellow ‘feeding wall’ which was more successful. The feeding wall consisted of a yellow plastic sticky trap placed in a polythene bag to protect the moths from the glue. Honey was smeared onto the polythene bag which was then fixed to the inside of the Perspex rearing cage (Figure 2.2).

Lettuce leaves were provided in the rearing cage in a white plastic tray for the moths to lay eggs on. The first eggs were recorded on 16 July, larvae and pupae from 23 July and new generation adults from 31 July. Leaves with eggs were transferred to a separate cage until the larvae were large enough to handle without damaging them. Larvae were then transferred to ventilated plastic boxes lined with tissue paper and with lettuce leaves as a food source. The boxes were cleaned every other day and any pupae removed and placed in the adult cage to allow them to emerge. A similar process was used to collect moths and produce larvae in 2016. Larvae were sent to Stockbridge Technology Centre for use in Trial 2 on 21 September 2015 and Trial 4 on 6 October 2016.

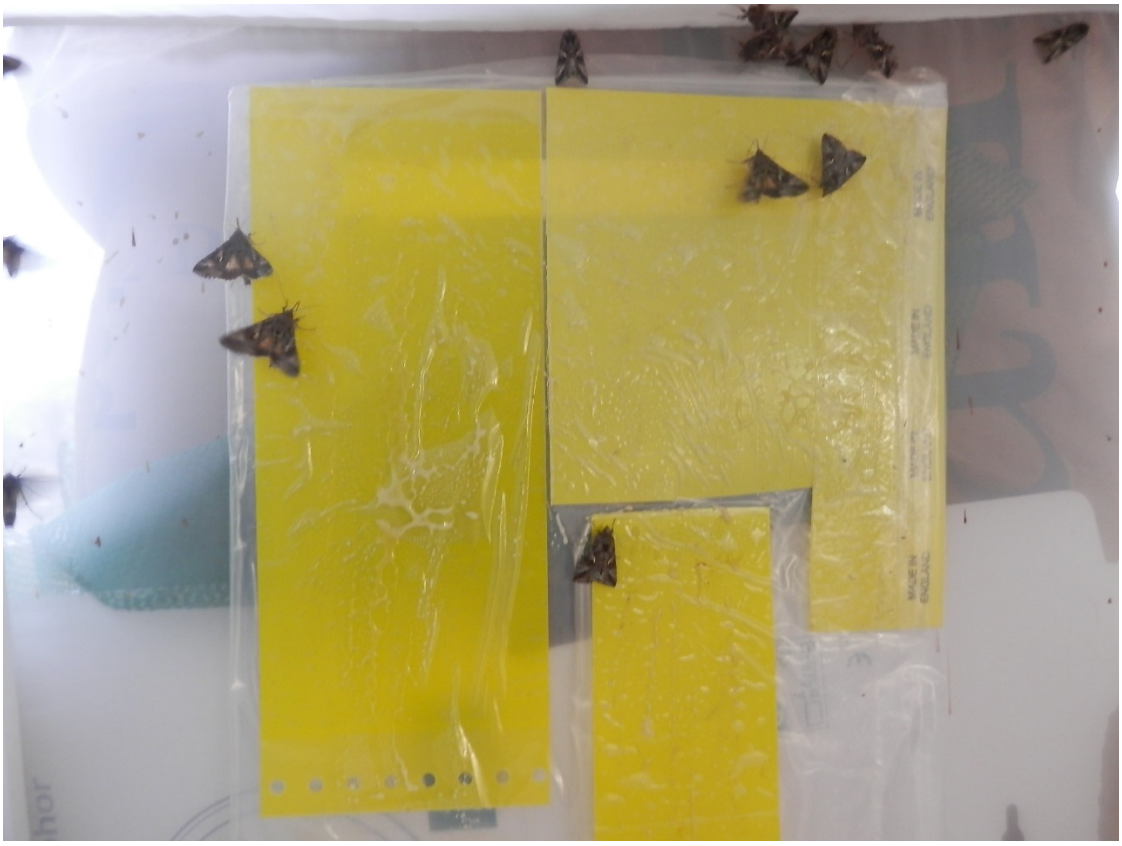


Figure 2.2. Adult Silver Y moths on the ‘feeding wall’ in the rearing cage at ADAS Boxworth.

Trials to evaluate insecticides and bioinsecticides

Three field trials were undertaken in 2015 to evaluate insecticides and bioinsecticides against silver Y moth (2 trials) and diamond-back moth (1 trial). All trials were infested with the target pest insects. Similarly, two field trials were undertaken in 2016 to evaluate insecticides and bioinsecticides against silver Y moth. Both trials were infested with silver Y moth. Finally a laboratory trial and a greenhouse trial were undertaken to evaluate insecticides and bioinsecticides against diamond-back moth.

Trial 1 Efficacy of insecticides and bioinsecticides against silver Y moth on whole head lettuce (Wellesbourne 2015).

Materials and methods

The trial focused on bioinsecticides, but included one insecticide (HDCI 090), and was undertaken to compare foliar spray treatments (5 treatments and untreated control). Lettuce seeds (cv. Challenge) were sown in P84 trays on 14 July 2016 and maintained in a glasshouse until transplanting. The trial was laid out in the field as an augmented Latin square design for 5 replicates of 6 treatments and was transplanted on 11 August. Each plot was 2.8 m x 1 bed and consisted of 4 rows x 9 plants at spacings of 35 cm between rows and 35 cm between plants. The trial was covered with netting to exclude birds and mammals. Small- to medium-sized larvae were selected from the laboratory culture at Warwick Crop Centre and counted into pots containing a piece of untreated lettuce leaf. Ten plants per plot were inoculated (6 larvae per plant) on 23-24 September 2015 by tipping the lettuce leaves with larvae attached into the centre of a lettuce. Treatments were chosen with regard to likely efficacy and potential for registration. All spray treatments (Table 2.1) were applied using a knapsack sprayer fitted with 02F110 nozzles in 300 l/ha water on 24 September. With the exception of HDCI 090, all the products were bioinsecticides.

The ten plants that had been inoculated were assessed for damage due to larval feeding on a 0-5 scale (0 = no damage, 1 = 1-5 holes, 2 = 6-10 holes, 3 = 11-20 holes and 5 = >20 holes) on 28 September (4 days after spraying). The numbers of larvae (live and dead) were counted on 30 September. Inoculated plants were sampled destructively as many of the living larvae had eaten into the lettuce. The key events of the trial are listed in Table 2.2.

Table 2.1. Treatments used in Trial 1

Code	Active ingredient	Product	Rate	Type
1	Untreated control			
2	HDCI 100		As specified by supplier	Bioinsecticide
3	Azadirachtin		As specified by supplier	Bioinsecticide
4	*Bt*	Lepinox Plus	As specified by supplier	Bioinsecticide
5	HDCI 089		As specified by supplier	Bioinsecticide
6	HDCI 090		As specified by supplier	Insecticide

Table 2.2. Key events in Trial 1

Date	Event
14-Jul	Seeds sown in P84s
11-Aug	Trial transplanted
23-Sep	Larva inoculation started
24-Sep	Larva inoculation completed
24-Sep	Sprays applied
28-Sep	Plant damage assessed
30-Sep	Larvae counted

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).

Results

For the analysis of the numbers of live and dead larvae remaining 4 days after treatment there was a statistically-significant effect of treatment on the numbers of dead larvae ($p=0.017$) and the numbers of live larvae ($p<0.001$) (Table 2.3; Figure 2.3). The insecticide HDCI 090 was the most effective treatment in both respects and the only treatment which significantly increased numbers of dead larvae and decreased numbers of live larvae compared with the untreated control. The other (bioinsecticide) treatments did not produce a statistically-significant effect.

For the analysis of the mean damage score there were no overall statistically-significant effects of treatment ($p=0.070$) (Figure 2.4), but a clear indication of a reduction in damage by HDCI 090 compared with the untreated control.

Table 2.3. Trial 1 - the mean numbers of dead and live silver Y moth larvae per plot 4 days after treatment.

Treatments	**Numbers of dead larvae**		**Numbers of live larvae**		**Damage score**
	SqRt	**Back trans**	**SqRt**	**Back trans**	
Untreated control	0.61	0.00	2.83	7.62	2.80
HDCI 100	0.70	0.11	3.68	13.17	2.51
Azadirachtin	1.04	0.70	3.52	11.99	2.72
Lepinox Plus	0.88	0.40	3.72	13.48	2.66
HDCI 089	1.07	0.77	3.45	11.50	2.40
HDCI 090	2.0	3.72	2.18	4.37	1.96
F-value	3.99		10.22		2.59
P-value	0.017		<0.001		0.070
SED	0.361		0.269		0.269
5% LSD	0.769		0.572		0.574
df	15		15		15

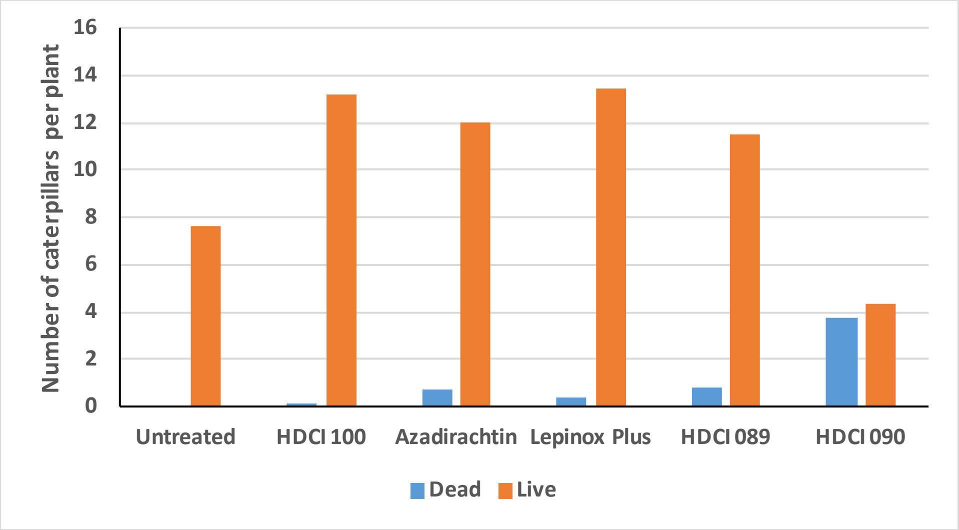


Figure 2.3. Trial 1 – the mean numbers of dead and live silver Y moth larvae per plot 4 days after treatment.

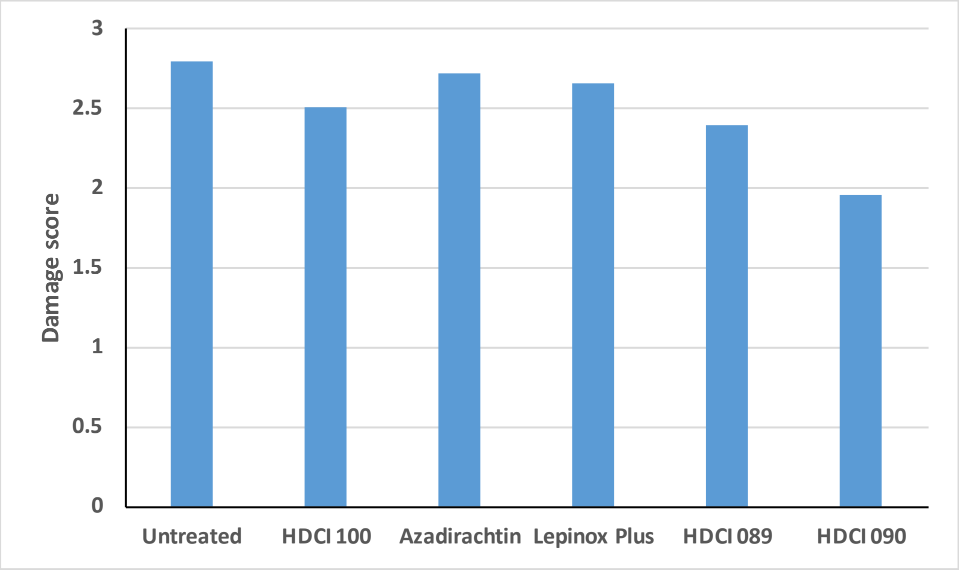


Figure 2.4. Trial 1 – the mean damage score due to feeding by silver Y moth larvae 4 days after treatment. ((0 = no damage, 1 = 1-5 holes, 2 = 6-10 holes, 3 = 11-20 holes and 5 = >20 holes)

Trial 2Efficacy of insecticides on silver Y moth in baby leaf lettuce (STC 2015)

Materials and methods

The trial considered insecticides and was conducted outdoors, under unprotected conditions, though the study site was surrounded by an electrified rabbit fence. Twenty-eight plots, measuring 3.6m metres long and 1.2m wide, were sown with baby leaf lettuce, *Lactuca sativa* var. Solavia RZ, at a rate of approximately 278 seeds per m^2 and 8 rows per plot (as advised by STC's Operations Manager), on 6 August 2015. Each plot was separated by 90 cm of bare soil to prevent spray drift between plots and treatments, with plots arranged according to a randomised block design.

Larvae were received from Warwick Crop Centre on the morning of 29 September 2015, and were immediately used to infest the plots. Thirty larvae were placed on plants in the central rows of each plot, and left to settle for at least four hours.

Treatments were chosen with regard to likely efficacy and potential for registration. On the afternoon of 29 September 2015, plots were treated with product, or a water control, by application at 3 bar pressure using an Oxford Precision Sprayer and F01 110 flat fan nozzles fitted to 3 outlets of a 4 outlet boom spray bar (the 4th outlet being blanked off). Table 2.4 summarises treatments and application rates; water rate was 300L/ha on account of plant size.

Table 2.4. Treatments used in Trial 2.

Code	**Active ingredient**	**Product**	**Rate**
1	Untreated control		
2	Lambda-cyhalothrin	Warrior	0.15 l/ha
3	Indoxacarb	Steward	0.085 kg/ha
4	Cyazypyr		As specified by supplier
5	Chlorantraniliprole [HDCI 096]	Coragen	As specified by supplier
6	Emamectin benzoate		As specified by supplier
7	HDCI 091		As specified by supplier

Two visual assessments for live larvae were made of the plots following treatment, with observations for phytotoxicity made at the same time.

The first, non-destructive, visual assessment was taken two days after treatment (1 October 2015). Each plant in a plot was examined for presence of live larvae, and the total number of live larvae found in each plot was recorded. The number of dead individuals was also recorded. Finally, the soil surface around the base of the plants was examined for larvae.

The second visual assessment was taken on the ninth and tenth days after treatment (8 and 9 October 2015). This assessment was taken destructively – each plant in the plot was uprooted and examined, to obtain a more accurate estimate of the numbers of larvae present. As per the first assessment, the total number of live larvae in each plot was recorded, and the number of dead individuals was also recorded.

Percentage mortality of larvae was Angular transformed prior to analysis. Data for 2 days after treatment and 9-10 days after treatment were 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).

Results

The results are presented in Table 2.5. Relatively low numbers of larvae were recovered (less than 50% of those released). For the data collected two days after treatment (Figure 2.5) and 9-10 days after treatment (Figure 2.6) there was a significant effect of treatment ($p = 0.001$ and $p < 0.001$, respectively). On both occasions all treatments led to lower numbers of larvae versus the control, except emamectin benzoate. On day 2, lambda-cyhalothrin also increased mortality compared with indoxacarb, emamectin benzoate and HDCI 091. No evidence of phytotoxicity was observed.

Table 2.5. Trial 2 – the mean percentage mortality of silver Y moth larvae 2 days after treatment.

Treatment	**2 days after spraying**		**9-10 days after spraying**	
	Ang	Back trans	Ang	Back trans
Untreated control	51.3	60.9	58.1	72.0
Lambda-cyhalothrin	85.4	99.4	90.0	100.0
Indoxacarb	71.3	89.7	87.4	99.8
Cyazypyr	80.2	97.1	83.6	98.8
Chlorantraniliprole	73.0	91.5	87.4	99.8
Emamectin benzoate	61.9	77.9	55.9	68.5
HDCI 091	68.0	86.0	83.6	98.8
F-value	6.11		24.82	
P-value	0.001		<0.001	
SED	6.48		4.13	
5% LSD	13.62		8.67	
df	18		18	

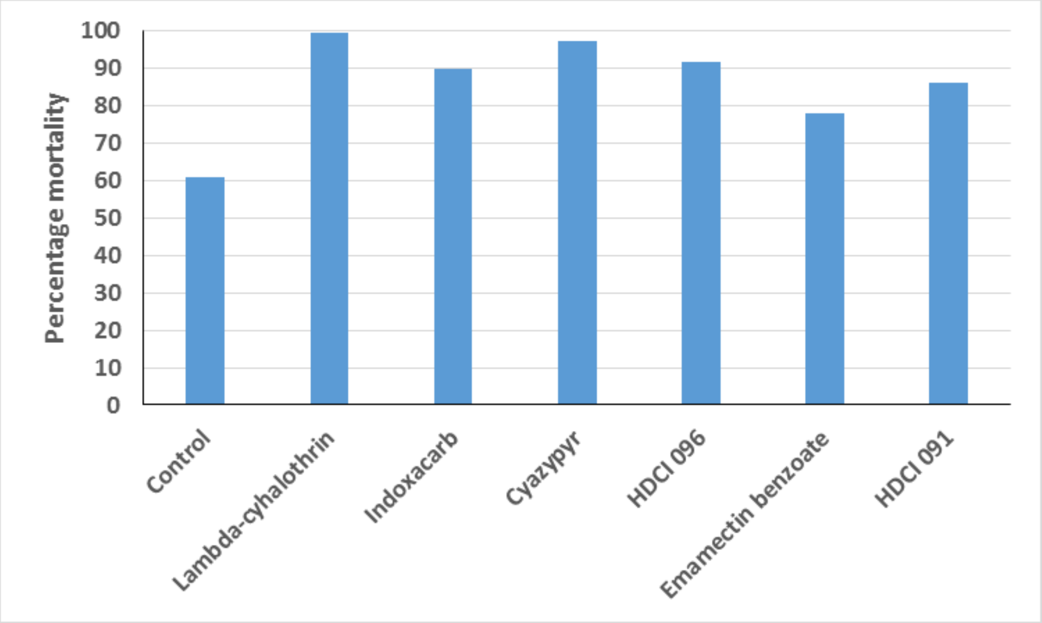


Figure 2.5. Mean percentage mortality of silver Y moth larvae 2 days after treatment. [HDCI 096 = Coragen (chlorantraniliprole)]

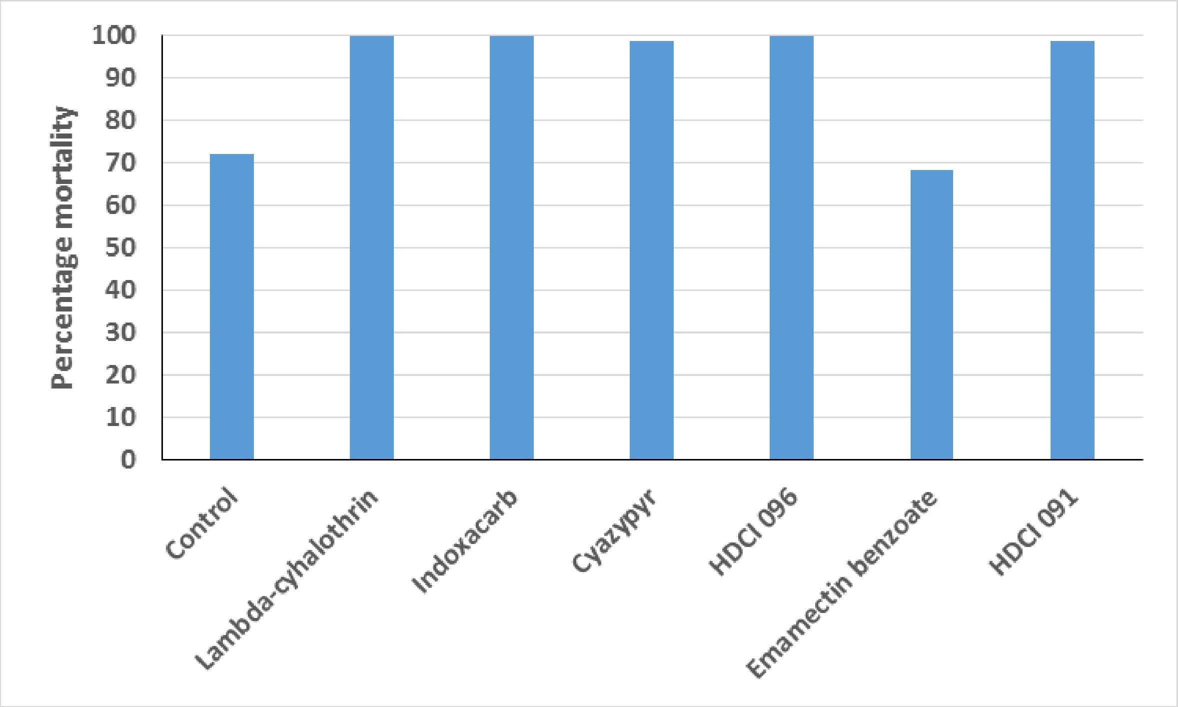


Figure 2.6. Mean percentage mortality of silver Y moth larvae 9-10 days after treatment.

[HDCI 096 = Coragen (chlorantraniliprole)]

Trial 3 Efficacy of insecticides and bioinsecticides against silver Y moth on whole head lettuce (Wellesbourne 2016).

Materials and methods

The trial was undertaken in 2016 to compare foliar spray treatments (5 treatments) and pre-planting drench treatments (2 treatments) with an untreated control. Treatments were chosen with regard to likely efficacy and potential for registration and the treatment list used in 2015 was extended to include two insecticides applied as pre-planting drench treatments. Lettuce seeds (cv. Saladin) were sown in P84 trays on 8 August 2016 and maintained in a glasshouse until transplanting outside. The two pre-planting drench treatments (Table 2.6) were applied on 31 August (1 day before planting) in 1 ml per module using a laboratory pipette. The treatments were washed on with a similar volume of water. The trial was laid out as a Trojan square design for 4 replicates of 8 treatments and was transplanted on 1 September. Each plot was 2.8 m x 1 bed and consisted of 4 rows x 9 plants at spacings of 35 cm between rows and 35 cm between plants. The trial was covered with fleece to exclude birds and mammals. Plants were inoculated by two means. Firstly, on 7-8 September, 10 plants per plot were inoculated with silver-Y eggs. Adult silver-Y moths from the laboratory culture at Warwick Crop Centre were allowed to lay on freshly introduced lettuce plants. The leaves were examined and cut into pieces containing 3 – 15 eggs. One leaf piece was wedged in the middle of each plant to be inoculated such that each plot received approximately 100 eggs. Secondly, small- to medium-sized larvae were selected from the laboratory culture at Warwick Crop Centre and counted into pots containing a piece of untreated lettuce leaf. An additional 10 plants per plot were inoculated (5 larvae per plant) on 21 September by tipping the lettuce leaves with larvae attached into the centre of a lettuce. All spray treatments (Table 2.7) were applied using a knapsack sprayer fitted with 02F110 nozzles in 300 l/ha water on 22 September. With the exception of HDCI 090, all the products were bioinsecticides.

The trial was assessed between 28 and 30 September (6 – 8 days after spraying). The inoculated plants were assessed for damage due to larval feeding by counting feeding holes and the numbers of larvae (live and dead) were counted. Inoculated plants (egg and larva) were sampled destructively as many of the living larvae had eaten into the lettuce. During the assessment it was noted that a number of plants had died and further investigation suggested that this was due to millipedes feeding on the roots and stems. Currant-lettuce aphid (*Nasonovia ribisnigri*) were also observed infesting some plants. The numbers of dead plants per plot and the numbers of assessed plants containing aphids were also recorded. The key events of the trial are listed in Table 2.7.

Table 2.6. Treatments used in Trial 3

Code	Active ingredient	Product	Rate	Type
1	Untreated control			
2	HDCI 100		As specified by supplier	Bioinsecticide
3	Azadirachtin		As specified by supplier	Bioinsecticide
4	*Bt*	Lepinox Plus	As specified by supplier	Bioinsecticide
5	HDCI 089 [1]		As specified by supplier	Bioinsecticide
6	HDCI 090		As specified by supplier	Insecticide
7	HDCI 103		Pre-planting drench treatment	Insecticide
8	HDCI 102		Pre-planting drench treatment	Insecticide

[1] Different formulation from 2015

Table 2.7. Key events in Trial 3

Date	Event
08-Aug	Seeds sown in P84s
31-Aug	Drench treatments applied
01-Sep	Trial transplanted
07-Sep	Egg inoculation started

08-Sep	Egg inoculation finished
21-Sep	Larva inoculation (5 larvae on 10 plants/plot)
22-Sep	Sprays applied
28-Sep	Damage and larva assessment started
30-Sep	Damage and larva assessment finished

The numbers of live larvae and the numbers of feeding holes in plants inoculated with eggs and larvae were analysed separately and combined. Percentage dead plants and percentage plants with aphids were Angular transformed prior to analysis. 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).

Results

Relatively small numbers of larvae were recovered. For the analysis of the numbers of feeding holes 6-8 days after treatment there was a statistically-significant effect of treatment on the numbers feeding holes in plants inoculated with eggs (p=0.018), larvae (p=0.037) or both combined (p=0.018) (Table 2.8; Figure 2.7). When considering the larval inoculation the pre-planting HDCI 103 significantly reduced numbers of holes compared with the untreated control and all other treatments. When considering both inoculations combined, HDCI 103 again significantly reduced numbers compared with the untreated control and all other treatments.

For the analysis of the numbers of live larvae 6-8 days after treatment there was a statistically-significant effect of treatment on the numbers of live larvae in plants inoculated with eggs (p=0.003) and in plants inoculated with either eggs or larvae (p=0.022) (Table 2.9; Figure 2.8). When considering the egg inoculation the pre-planting treatment HDCI 103 (which had no live larvae) significantly reduced numbers compared with the untreated control and Lepinox Plus and HDCI 089. When considering both inoculations combined, HDCI 103 again significantly reduced numbers compared with the untreated control and Lepinox Plus and HDCI 089. Also, the insecticide HDCI 090 significantly reduced numbers compared with the untreated control and Lepinox Plus.

Table 2.8. Trial 3 - the mean numbers of live silver Y moth larvae per plant 6-8 days after spraying, following different inoculation methods.

	Inoculation		
Treatments	**Larva**	**Egg**	**Combined**
Untreated control	0.300	0.268	0.268
HDCI 100	0.075	0.093	0.093
Azadirachtin	0.231	0.169	0.169
Lepinox Plus	0.269	0.354	0.354
HDCI 089	0.200	0.209	0.209
HDCI 090	0.075	0.079	0.079
HDCI 103	0.000	0.000	0.000
HDCI 102	0.200	0.133	0.133
F-value	1.89	4.88	3.20
P-value	0.131	0.003	0.022
SED	0.110	0.090	0.089
5% LSD	0.230	0.188	0.187
Df	18	18	18

The analyses of percentage dead plants (p=0.122) and percentage plants with aphids (p=0.494) were not significant. The results are shown in Table 2.10. However, it can be seen that, in contrast to all other treatments, very few plants treated with HDCI 103 died (Figure 2.9) and the percentage of plants with aphids was lower in all treatments than in the untreated control (Figure 2.10).

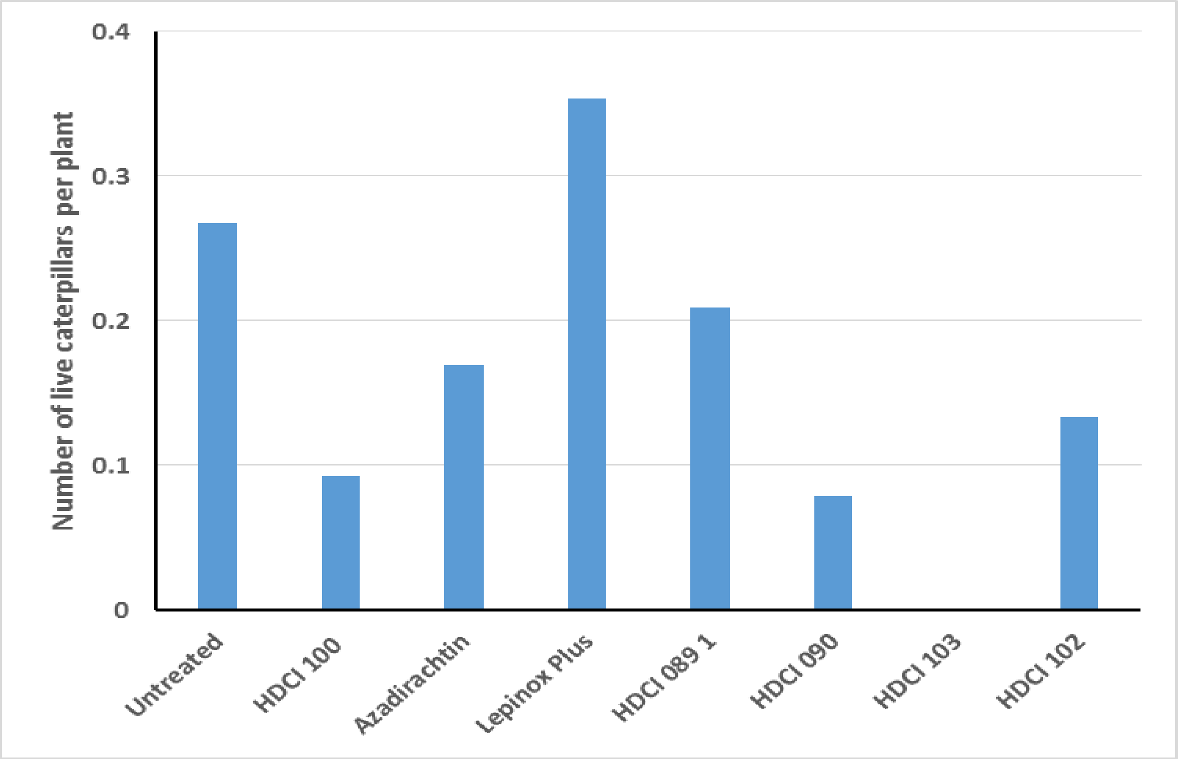


Figure 2.7. Trial 3 - the mean numbers of live silver Y moth larvae per plant 6-8 days after spraying (egg and larval inoculations combined).

Table 2.9. Trial 3 - the mean numbers of feeding holes per plant 6-8 days after spraying.

	Inoculation		
Treatments	**Larva**	**Egg**	**Combined**
Untreated control	13.30	8.45	11.03
HDCI 100	10.22	10.61	10.37
Azadirachtin	10.80	10.42	10.62
Lepinox Plus	14.42	10.76	12.83
HDCI 089	9.97	8.81	9.40
HDCI 090	6.97	8.52	7.76
HDCI 103	2.55	1.31	1.93
HDCI 102	12.15	4.26	8.76
F-value	2.80	3.36	3.37
P-value	0.037	0.018	0.018
SED	3.198	2.609	2.522
5% LSD	6.720	5.482	5.298
df	18	18	18

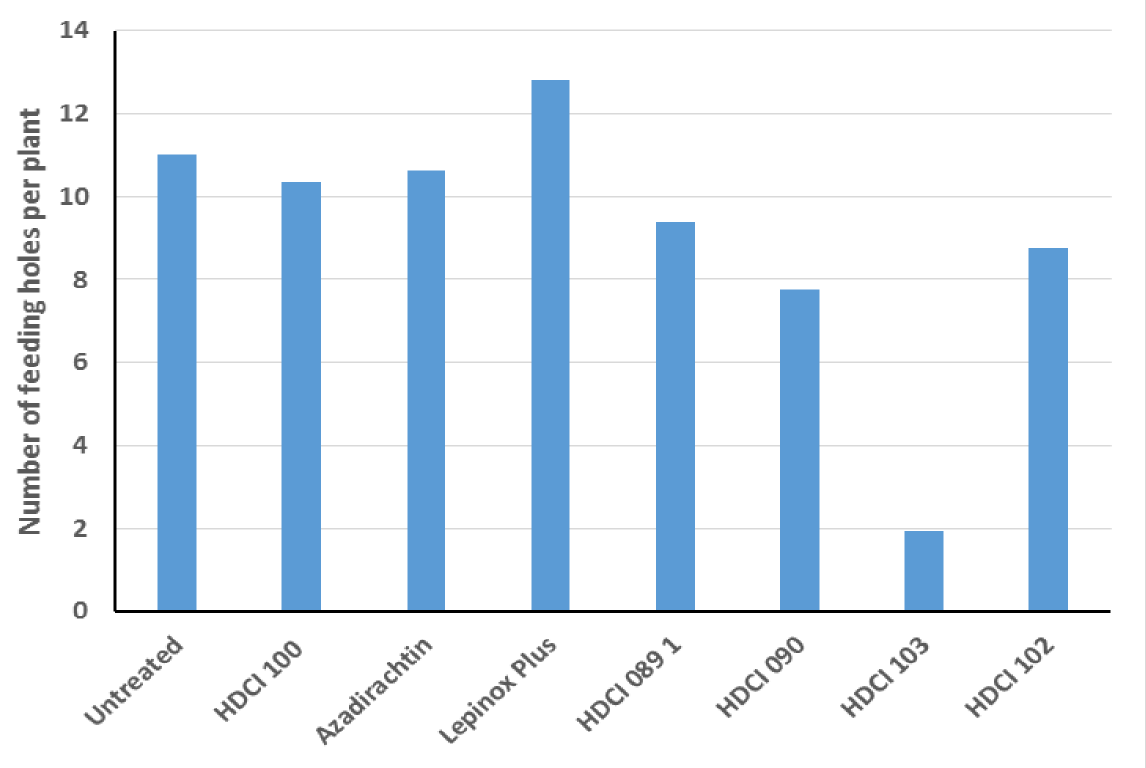


Figure 2.8. Trial 3 - the mean numbers of feeding holes per plant 6-8 days after spraying (egg and larva inoculations combined).

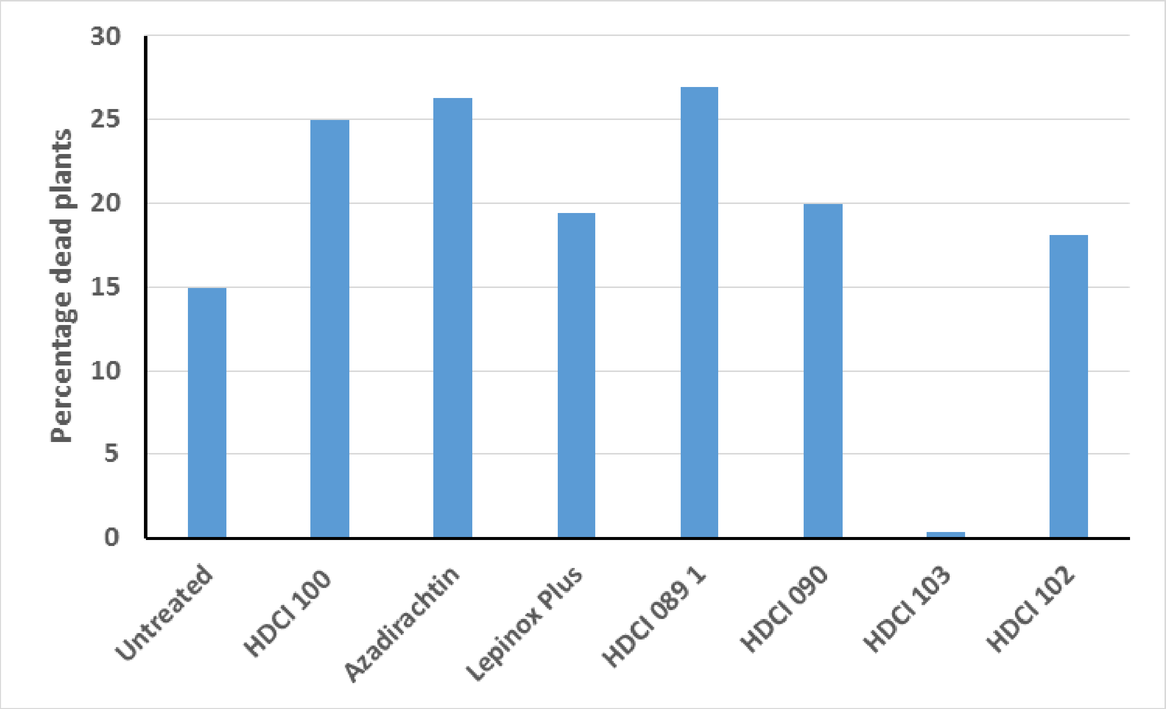


Figure 2.9. Trial 3 - the mean percentage dead plants per plot 6-8 days after spraying.

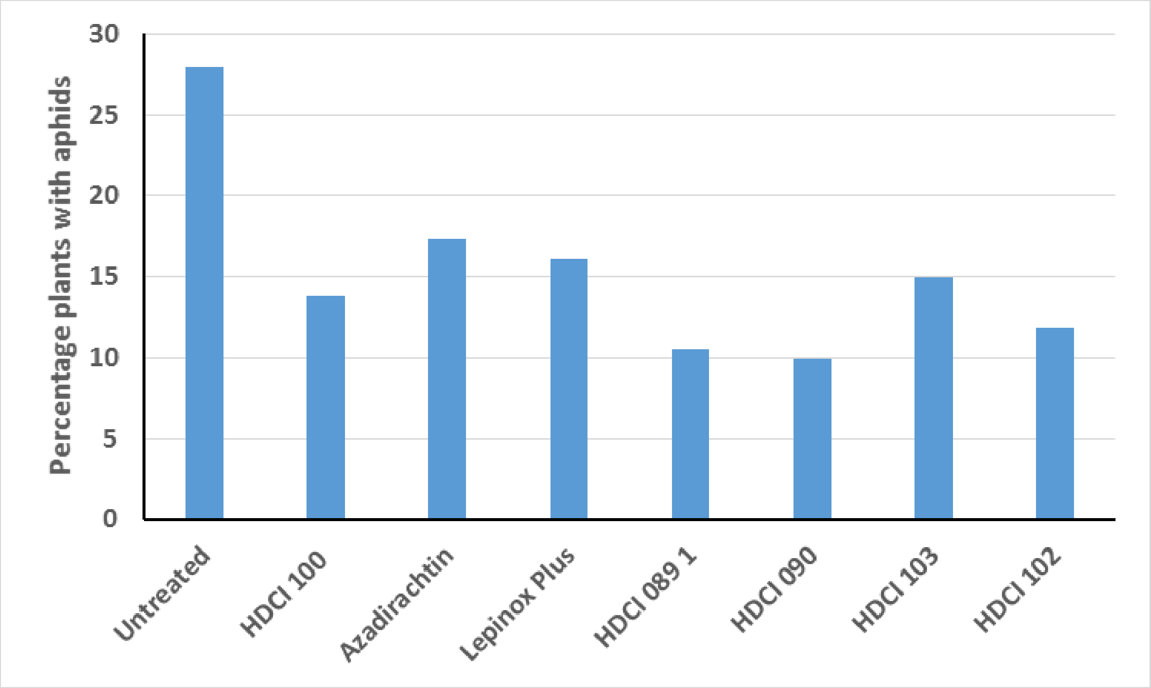


Figure 2.10. Trial 3 - the mean percentage of assessed plants with aphids 6-8 days after spraying.

Table 2.10. Trial 3 - the percentage dead plants and the percentage plants with aphids 6-8 days after spraying.

Treatments	% Dead plants		% With aphids	
	Ang	Back trans	Ang	Back trans
Untreated control	22.7	14.9	32.0	28.0
HDCI 100	30.0	25.0	21.8	13.8
Azadirachtin	30.9	26.3	24.6	17.3
Lepinox Plus	26.1	19.4	23.7	16.1
HDCI 089	31.3	26.9	18.9	10.5
HDCI 090	26.5	20.0	18.4	9.9
HDCI 103	3.2	0.3	22.8	15.0
HDCI 102	25.2	18.1	20.1	11.8
F-value	1.94		0.95	
P-value	0.122		0.494	
SED	9.24		6.28	
5% LSD	19.40		13.19	
df	18		18	

Trial 4Efficacy of insecticides and bioinsecticides on silver Y moth in baby leaf lettuce (STC 2016)

Materials and methods

The trial was conducted outdoors at STC, under unprotected conditions, though the study site was surrounded by an electrified rabbit fence. Twenty-eight plots, measuring 3.6m metres long and 1.2m wide, were sown with baby leaf lettuce, *Lactuca sativa* var. Solavia RZ, at a rate of approximately 278 seeds per m^2 and 8 rows per plot (as advised by STC's Operations Manager), on the 17 August 2016. Each plot was separated by 90 cm of bare soil to prevent spray drift between plots and treatments, with plots arranged according to a randomised block design.

Larvae were received from ADAS late morning of 6 October 2016, and were used to artificially infest the plots that afternoon. Thirty larvae were placed on plants in the central rows of each plot, and left undisturbed to settle.

Treatments were the same as those evaluated in 2015, to confirm their activity. On the afternoon of 7 October 2016, plots were treated with product, or a water control, by application at 3 bar pressure using an Oxford Precision Sprayer and F01 110 flat fan nozzles fitted to 3 outlets of a 4 outlet boom spray bar (the 4th outlet being blanked off). Table 2.11 summarises treatments and application rates; water rate was 300L/ha on account of plant size.

Table 2.11 Treatments used in Trial 4.

Code	Active ingredient	Product	Rate
1	Untreated control		
2	Lambda-cyhalothrin	Ninja	0.15 l/ha
3	Indoxacarb	Steward	0.085 kg/ha
4	Cyazypyr		As specified by supplier
5	Chlorantraniliprole	Coragen	As specified by supplier
6	Emamectin benzoate		As specified by supplier
7	HDCI 091		As specified by supplier

Two visual assessments for live larvae were made of the plots following treatment, with observations of plant growth stage, phytotoxicity and phytostimulation also made at the same time.

The first, non-destructive visual assessment was taken three days after treatment (10 October 2016). Each plant in a plot was examined for presence of live larvae (all plants), and the total number of live larvae found in each treatment plot was recorded. The number of dead individuals was also noted. The soil surface around the base of the plants was also examined for larvae.

The second visual assessment was taken on the tenth day after treatment (17 October 2016). This assessment was taken destructively – each plant in the plot was uprooted and examined, to obtain a more accurate reflection of larvae present. As per the first assessment, the total number of live larvae in each treatment plot was recorded, and the number of any dead individuals also noted.

Percentage mortality of larvae was Angular transformed prior to analysis. Data for 3 days after treatment and 10 days after treatment were 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).

Results

The results are presented in Table 2.12.

Relatively low numbers of larvae were recovered (less than 50% of those released). For the data collected 3 days after treatment (Figure 2.11) and 10 days after treatment (Figure 2.12) there was a significant effect of treatment ($p = 0.003$ and $p < 0.001$ respectively). After 3 days lambda-cyhalothrin, indoxacarb and cyazypyr had reduced numbers of larvae compared with the control and emamectin benzoate. Chlorantraniliprole and HDCI 091 had also reduced numbers but not significantly. Lambda-cyhalothrin also increased mortality compared with chlorantraniliprole. After 10 days, all treatments except emamectin benzoate had reduced numbers of larvae compared with the control and emamectin benzoate. Lambda-cyhalothrin and chlorantraniliprole had also reduced numbers compared with HDCI 091. No evidence of phytotoxicity was observed.

Table 2.12. Trial 4 – the mean percentage mortality of silver Y moth larvae 3 and 10 days after treatment.

Treatment	**3 days after spraying**		**10 days after spraying**	
	Ang	Back trans	Ang	Back trans
Untreated control	56.3	69.1	61.3	76.9
Lambda-cyhalothrin	87.4	99.8	87.4	99.8
Indoxacarb	74.2	92.6	83.6	98.8
Cyazypyr	73.7	92.1	81.0	97.6
Chlorantraniliprole	64.1	80.9	90.0	100.0
Emamectin benzoate	57.5	71.2	62.6	78.7
HDCI 091	70.1	88.4	78.3	95.9
F-value	5.31		13.92	
P-value	0.003		<0.001	
SED	6.65		4.35	
5% LSD	13.98		9.14	
df	18		18	

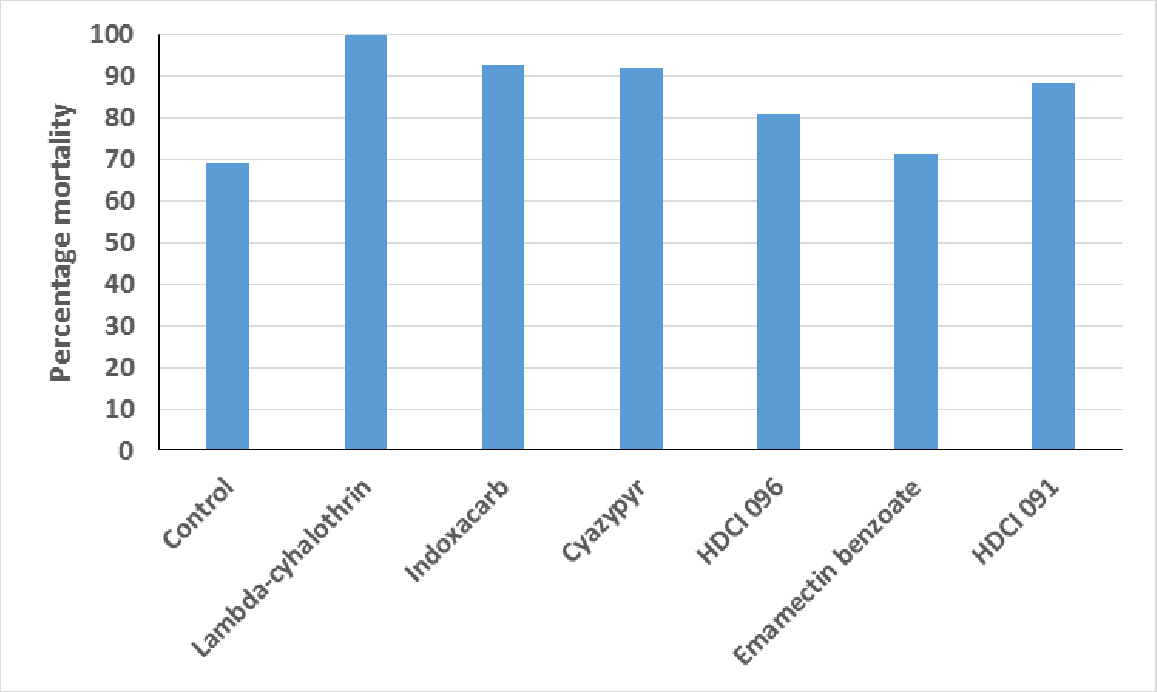


Figure 2.11. Mean percentage mortality of silver Y moth larvae 3 days after treatment.

[HDCI 096 = Coragen (chlorantraniliprole)]

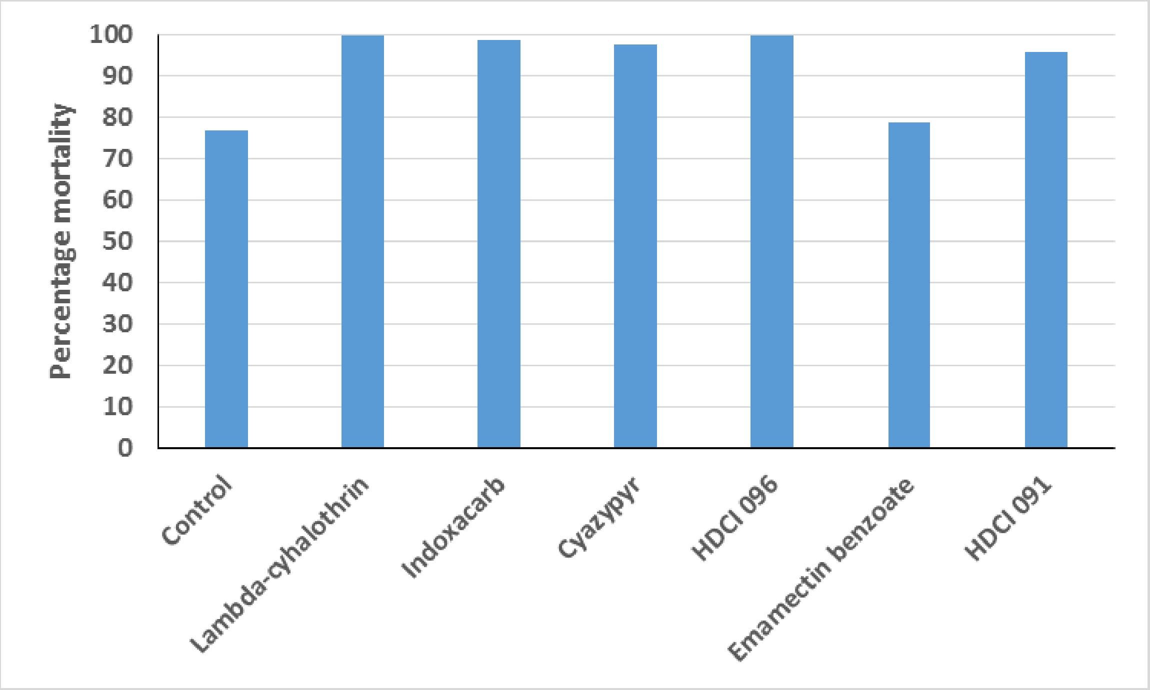


Figure 2.12. Mean percentage mortality of silver Y moth larvae 10 days after treatment.

[HDCI 096 = Coragen (chlorantraniliprole)]

Trial 5 Efficacy of insecticides and bioinsecticides on diamond-back moth (Wellesbourne 2015)

Materials and methods

The trial was undertaken to compare foliar spray treatments (6 treatments and untreated control) (Table 2.13). Brussels sprout seeds (cv Faunus F1) were sown in 308 Hassy trays on 12 May and maintained in a glasshouse until transplanting. The trial was laid out as a Youden Rectangle for 4 replicates of 7 treatments and was transplanted on 23 June. Each plot was 3.5 m x 1 bed and consisted of 3 rows x 8 plants at spacings of 50 cm between rows and 50 cm between plants. The trial was covered with netting to exclude birds and mammals. In the absence of a natural infestation the trial was inoculated with diamond-back moths from the continuous culture maintained within the Insect Rearing Unit at Warwick Crop Centre.

Adult moths were allowed to lay eggs for 3 days on pot-grown Brussels sprout plants. Portions of leaves were selected which contained approximately 6 eggs or very small larvae. This task was made more difficult by the moths' habit of laying eggs in preference on the plastic pots so portions of pot were also selected as appropriate. The selected leaf/pot pieces were attached to marked plants with paper clips. Over the period 4 -24 September 7 plants/plot were inoculated on 2 occasions each. All spray treatments (Table 2.14) were applied using a knapsack sprayer fitted with 02F110 nozzles in 400 l/ha water on 25 September.

The plants were assessed for damage due to larval feeding (numbers of feeding holes on inoculated leaves) and the numbers of larvae (live and pupae) were counted on 1 October. The key events of the trial are listed in Table 2.14.

Table 2.13 Treatments used in Trial 5.

Code	Active ingredient	Product	Rate
1	Untreated control		
2	Cyazypyr		As specified by supplier
3	Azadirachtin		As specified by supplier
4	Chlorantraniliprole	Coragen	As specified by supplier
5	Emamectin benzoate		As specified by supplier
6	HDCI 100		As specified by supplier
7	*Bt*	Lepinox Plus	As specified by supplier

Table 2.14 Key events in Trial 3

Date	Event
12-May	Seeds sown in 308 Hassy trays
23-Jun	Trial transplanted
04-Sep	Larva inoculation started
24-Sep	Larva inoculation finished
25-Sep	Sprays applied
28-Sep	Damage and larva assessment

Results

The numbers of larvae recovered during assessment of the plots were too low (<1 per plant) for meaningful analysis of the data.

Trial 6 Efficacy of insecticides and bioinsecticides on diamond-back moth (Wellesbourne 2016)

Materials and methods

As the field trial on diamond-back moth in 2015 was unsuccessful due to low recovery of larvae, a laboratory trial was performed as agreed with the project steering group. The trial was conducted within the Insect Rearing Unit at Warwick Crop Centre.

Twenty pot-grown Brussels sprout plants were placed in a cage with adult diamond-back moths. The moths were allowed to lay eggs for three days before the plants were removed to another cage. Larvae were allowed to develop for 7 days and medium-sized larvae were transferred to fresh plants (6 plants per treatment and 5 larvae per plant). The larvae were allowed to establish for a further day before spraying.

Plants were taken outside and removed from cages before spraying. The treatments (Table 2.15) were applied using a knapsack sprayer fitted with 02F110 nozzles in 300 l/ha water. The plants were returned to their cages and kept at 20ºC for two days before the numbers of feeding holes and the numbers of live larvae were assessed. The trial was repeated on three occasions. The key events are listed in Table 2.16

Table 2.15 Treatments used in Trial 6.

Code	Active ingredient	Product	Rate
1	Untreated control		
2	Spinosad	Tracer	0.2 l/ha
3	Cyazypyr		As specified by supplier
4	Azadirachtin		As specified by supplier
5	Chlorantraniliprole	Coragen	As specified by supplier
6	Emamectin benzoate		As specified by supplier
7	HDCI 100		As specified by supplier
8	*Bt*	Lepinox Plus	As specified by supplier

Table 2.16 Key events in Trial 6

Date	Event
29-Feb	Egg laying started
10-Mar	Test plants inoculated with larvae
11-Mar	Sprays applied
14-Mar	Day 3 larva and damage assessment
17-Mar	Day 6 larva and damage assessment
21-Mar	Day 10 larva and damage assessment
20-Mar	Egg laying started
31-Mar	Test plants inoculated with larvae
1-Apr	Sprays applied
4-Apr	Day 3 larva and damage assessment
7-Apr	Day 6 larva and damage assessment
11-Apr	Day 10 larva and damage assessment
11/Apr	Egg laying started
21-Apr	Test plants inoculated with larvae
22-Apr	Sprays applied
25-Apr	Day 3 larva and damage assessment
28-Apr	Day 6 larva and damage assessment
2-May	Day 10 larva and damage assessment

The percentage live larvae (after Angular transformation) and the numbers of feeding holes were analysed. 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).

Results

The results for the mean percentage live larvae recovered (based on the numbers used to infest the plants at the start of the trial) and and the mean number of feeding holes per plant are presented in Tables 2.17 and 2.18 and Figures 2.13 and 2.14. All analyses were significant ($p < 0.001$). Percentage live larvae declined over time. Three days after spraying all treatments had reduced the percentage live larvae compared with the untreated control and continued to do so after 6 and 10 days. Spinosad, cyazypyr, chlorantraniliprole and Lepinox Plus were the most effective with 100% mortality after 3 days. The other treatments had significantly more live larvae after 3 days. After 6 days virtually all larvae had died in the

HDCI 100 treatment. Azadirachtin and emamectin benzoate were less effective at both assessment dates. After 10 days this pattern continued but mortality continued to increase with azadirachtin and emamectin benzoate. The pattern for feeding holes was very similar with all treatments reducing holes compared with the untreated control on all 3 assessment occasions. Spinosad, cyazypyr, chlorantraniliprole and Lepinox Plus reduced holes compared with HDCI 100, azadirachtin and emamectin benzoate. HDCI 100 reduced the number of holes compared with azadirachtin and emamectin benzoate.

Table 2.17. Trial 6 - the mean percentage live diamond-back moth larvae 3, 6 and 10 days after spraying.

Treatments	**3 days**		**6 days**		**10 days**	
	Ang	Back trans	Ang	Back trans	Ang	Back trans
Untreated control	50.23	59.08	48.93	56.84	47.58	54.49
Spinosad	0.00	0.00	0.00	0.00	0.00	0.00
Cyazypyr	0.00	0.00	0.00	0.00	0.00	0.00
Azadirachtin	38.42	38.62	28.29	22.45	9.98	3.00
Coragen	0.00	0.00	0.00	0.00	0.00	0.00
Emamectin benzoate	35.80	34.21	20.42	12.18	9.98	3.00
HDCI 100	30.49	25.74	4.99	0.76	0.00	0.00
Lepinox Plus	0.00	0.00	0.00	0.00	0.00	0.00
F-value	52.72		36.00		38.19	
P-value	<0.001		<0.001		<0.001	
SED	4.17		4.29		3.76	
5% LSD	8.95		9.20		8.07	
df	14		14		14	

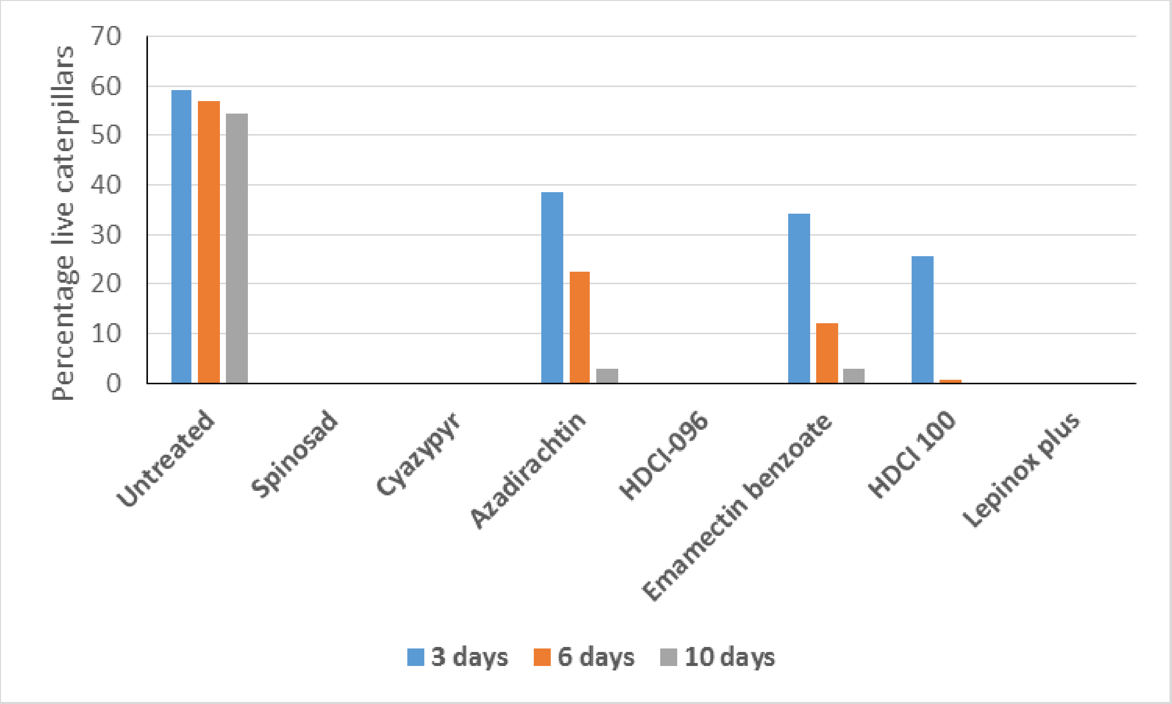


Figure 2.13. Trial 6 - the mean percentage live diamond-back moth larvae 3, 6 and 10 days after spraying. [HDCI 096 = Coragen (chlorantraniliprole)]

Table 2.18. Trial 6 - the mean number of feeding holes caused by diamond-back moth larvae 3, 6 and 10 days after spraying.

Treatments	**3 days**	**6 days**	**10 days**
Untreated control	42.1	59.2	63.1
Spinosad	7.5	7.5	7.5
Cyazypyr	8.3	8.3	8.3
Azadirachtin	27.9	28.7	28.9
Coragen	8.4	8.4	8.4
Emamectin benzoate	24.2	29.8	29.8
HDCI 100	16.8	19.0	18.6
Lepinox Plus	7.3	7.3	7.3
F-value	41.50	12.41	28.51
P-value	<0.001	<0.001	<0.001
SED	2.79	7.26	5.11
5% LSD	5.98	15.58	10.96
df	14	14	14

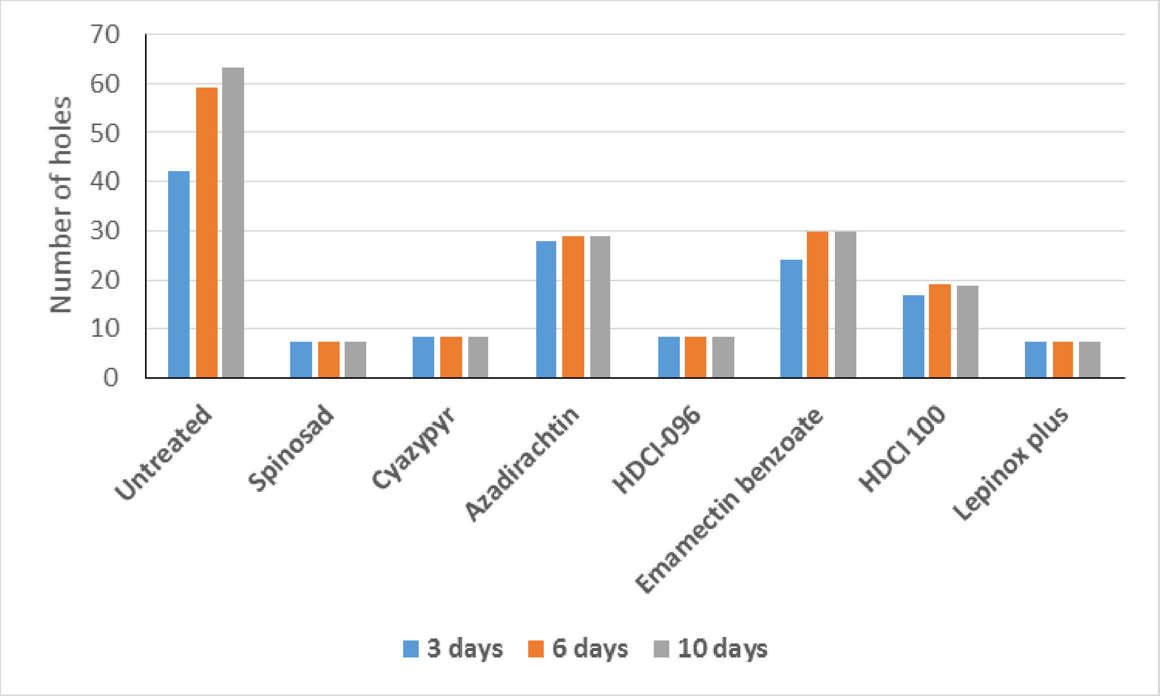


Figure 2.14. Trial 6 – the mean number of feeding holes per plant 3, 6 and 10 days after treatment. [HDCI 096 = Coragen (chlorantraniliprole)]

Trial 7 Efficacy of insecticides and bioinsecticides on diamond-back moth (Wellesbourne 2016-17)

Materials and methods

As the field trials with diamond-back moth proved problematic in 2015 a glasshouse trial was planned. There was a large migration of diamond-back moth in 2016 and a number of individuals were collected (as larvae) in a polytunnel at Warwick Crop Centre. This population was allowed to multiply within a laboratory area until sufficient numbers were available for the spray trial. The treatments were the same as those used in Trial 4 with the addition of Hallmark (lambda-cyhalothrin – pyrethroid). The trial was conducted within a glasshouse at Warwick Crop Centre.

Thirty six pot-grown Brussels sprout plants were placed into four cages (9 plants per cage) with adult diamond-back moths (175 per cage) on 10 January 2017. The moths were allowed to lay eggs for three days before the plants were removed. Each plant was transferred to a separate cage along with one other fresh plant and transferred to the glasshouse. Soon after transfer a boiler failure and subsequent temperature control problems meant that the temperature within the glasshouse remained low for several days which halted the development of the diamond-back moth larvae. On 8 February 2017 the majority of the larvae were 2nd instar and were sufficiently large to count. After counting a further 3 fresh plants were added to each cage. The plants were left until 14 February to allow the larvae to move around the fresh plants. Plants were then taken outside and removed from cages before spraying. The treatments (Table 2.19) were applied using a knapsack sprayer fitted with 02F110 nozzles in 300 l/ha water. The plants were returned to their cages and arranged in a 3 x 3 lattice square design of 4 replicates by 9 treatments. The cages were kept at 18°C for three days before the numbers of feeding holes and the numbers of live larvae were assessed. Feeding holes and live larvae were assessed again 6 and 10 days after spraying. The key events are listed in Table 2.20

Table 2.19. Treatments used in Trial 7.

Code	Active ingredient	Product	Rate
1	Untreated control		
2	Spinosad	Tracer	0.2 l/ha
3	Cyazypyr		As specified by supplier
4	Azadirachtin		As specified by supplier
5	Chlorantraniliprole	Coragen	As specified by supplier
6	Emamectin benzoate		As specified by supplier
7	HDCI 100		As specified by supplier
8	*Bt*	Lepinox Plus	As specified by supplier
9	Lambda-cyhalothrin	Hallmark	0.1 l/ha

Table 2.20 Key events in Trial 7

Date	Event
10-Jan	Egg laying started
13-Jan	Plants moved to glasshouse
8-Feb	Pre-spray larva count
14-Feb	Sprays applied
17-Feb	Day 3 larva and damage assessment
21-Mar	Day 6 larva and damage assessment
20-Mar	Day 10 larva and damage assessment

The percentage live larvae (after Angular transformation) and the numbers of feeding holes in the four plants which were not inoculated (after Square root transformation) were analysed. The trial was arranged as a 3 x 3 lattice square but for analysis it was assumed that each replicate block was fully randomised. 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).

Results

The results for the mean percentage live larvae recovered (based on the pre-spray counts) and the mean number of feeding holes per non-inoculated plant are presented in Tables 2.21 and 2.22 and Figures 2.15 and 2.16.

All analyses of percentage live larvae were significant ($p < 0.001$). Percentage live larvae declined over time. Three days after spraying spinosad, cyazypyr, azadirachtin, chlorantraniliprole and Lepinox Plus had reduced the percentage live larvae compared with the untreated control. Spinosad and cyazypyr had also reduced the percentage of larvae compared with all other treatments and chlorantraniliprole had reduced the percentage of larvae compared with all other treatments except spinosad and cyazypyr. After 6 days the percentage of live larvae had continued to decline and all treatments except emamectin benzoate had reduced the percentage of live larvae compared with the untreated control. Spinosad and cyazypyr had also reduced the percentage compared with azadirachtin, emamectin benzoate, HDCI-100 and lambda-cyhalothrin. Azadirachtin, chlorotraniliprole and Lepinox Plus reduced the percentage compared to emamectin benzoate, HDCI-100 and lambda-cyhalothrin. HDCI-100 reduced the percentage compared with emamectin benzoate and lambda-cyhalothrin. After 10 days virtually all larvae were dead in the spinosad, cyazypyr, chlorantraniliprole and Lepinox Plus treatments and all treatments except emamectin benzoate had reduced the percentage of live larvae compared with the untreated control. Spinosad, cyazypyr, azadirachtin and Lepinox Plus reduced the percentage compared with emamectin benzoate, HDCI-100 and lambda-cyhalothrin. HDCI-100 reduced the percentage compared with emamectin benzoate and lambda-cyhalothrin.

The effect of treatment on the number of feeding holes was not significant until 10 days after spraying ($p = 0.001$). At this time all treatments except emamectin benzoate and lambda-cyhalothrin had reduced numbers of holes compared with the untreated control. Spinosad, cyazypyr, azadirachtin, CHLORANTRANILIPROLE and Lepinox Plus had also reduced numbers of holes compared with emamectin benzoate and lambda-cyhalothrin

Table 2.21. Trial 7 - the mean percentage live diamond-back moth larvae 3, 6 and 10 days after spraying.

Treatments	**3 days**		**6 days**		**10 days**	
	Ang	Back trans	Ang	Back trans	Ang	Back trans
Untreated control	90.00	100	78.54	96.1	76.72	94.7
Spinosad	14.19	6.0	2.40	0.2	2.40	0.2
Cyazypyr	28.08	22.2	2.05	0.1	0.00	0.0
Azadirachtin	65.00	82.1	22.55	14.7	8.39	2.1
Chlorantraniliprole	45.61	51.1	11.99	4.3	0.00	0.0
Emamectin benzoate	85.03	99.3	73.99	92.4	67.44	85.3
HDCI 100	77.88	95.6	42.43	45.5	19.15	10.8
Lepinox Plus	74.85	93.2	23.06	13.4	0.00	0.0
Lambda-cyhalothrin	77.04	95.0	62.53	78.7	60.27	75.4
F-value	30.96		60.89		93.97	
P-value	<0.001		<0.001		<0.001	
SED	6.77		5.44		4.73	
5% LSD	13.97		11.22		9.76	
df	24		24		24	

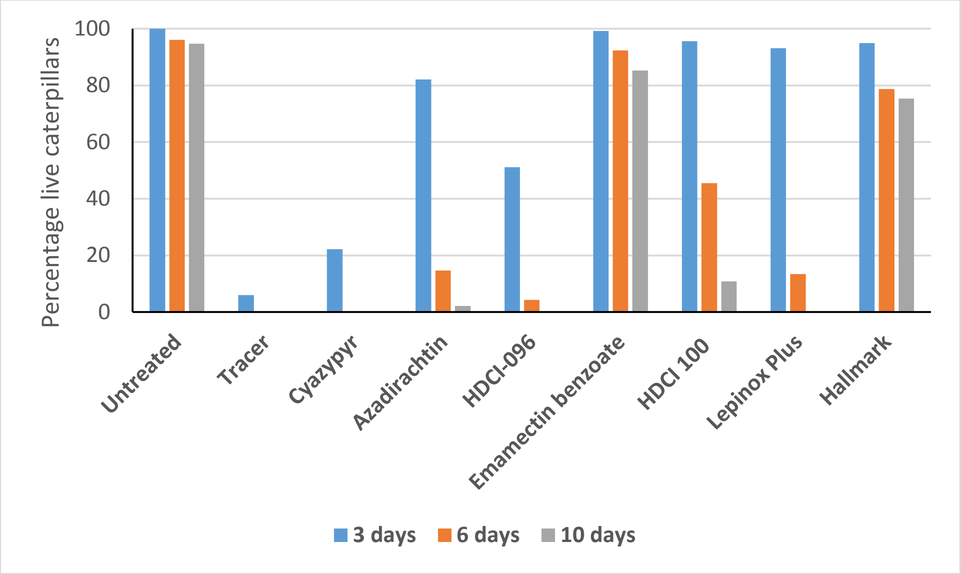


Figure 2.15. Trial 7 - the mean percentage live diamond-back moth larvae 3, 6 and 10 days after spraying.

Table 2.22. Trial 7 - the mean number of feeding holes in non-inoculated plants caused by diamond-back moth larvae 3, 6 and 10 days after spraying.

Treatments	3 days		6 days		10 days	
	Sq Rt	Back trans	Sq Rt	Back trans	Sq Rt	Back trans
Untreated control	6.24	38.9	9.24	85.4	11.10	123.1
Spinosad	4.87	23.7	5.01	25.1	5.01	25.1
Cyazypyr	4.10	16.8	4.34	18.8	4.34	18.8
Azadirachtin	4.32	18.6	4.87	23.7	5.23	27.4
Chlorantraniliprole	4.19	17.6	4.56	20.8	4.63	21.4
Emamectin benzoate	5.50	30.2	7.51	56.4	9.93	98.6
HDCI 100	5.42	29.4	6.81	46.3	7.11	50.6
Lepinox Plus	5.08	25.8	5.28	27.8	5.44	29.6
Lambda-cyhalothrin	5.08	25.8	7.11	50.5	9.36	87.6
F-value	0.51		2.33		4.91	
P-value	0.835		0.052		0.001	
SED	1.382		1.545		1.645	
5% LSD	2.853		3.189		3.394	
df	24		24		24	

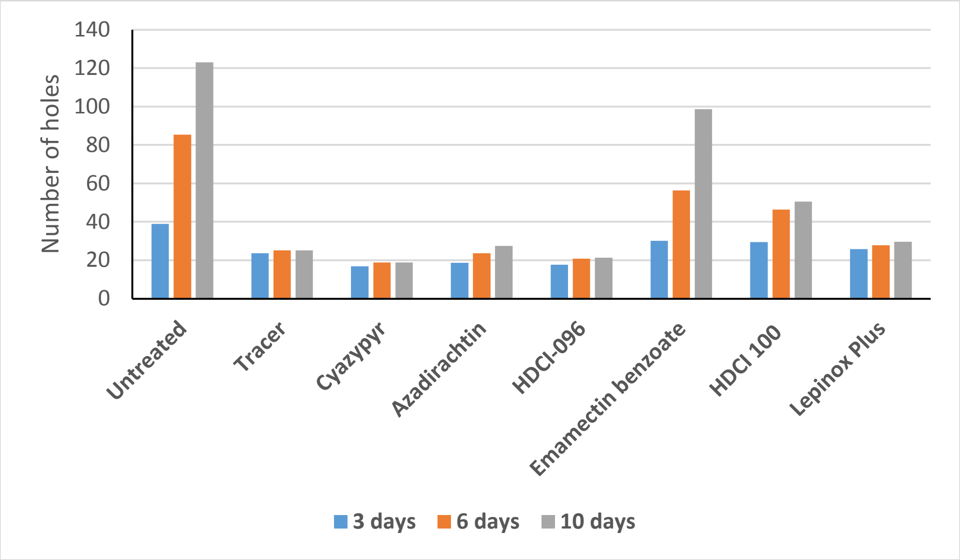


Figure 2.16. Trial 7 – the mean number of feeding holes per plant 3, 6 and 10 days after treatment.

Monitoring adults and larvae (Objectives 5 and 6)

Objective 5	Develop a risk-based spray decision-making system linked to trapping of moths and measure its efficacy, via field trials, against normal pest control practice.

Historical data

Historical data on the abundance/activity of silver Y moth, diamond-back moth and turnip moth were available from various sources and are summarised below.

Silver Y moth

Figure 3.1 summarises captures made by the network of light traps run by the Rothamsted Insect Survey over the last 50 years in England and Wales and in Scotland and shows that there is considerable variation in overall abundance from year to year but that overall, on average, numbers have neither increased or decreased.

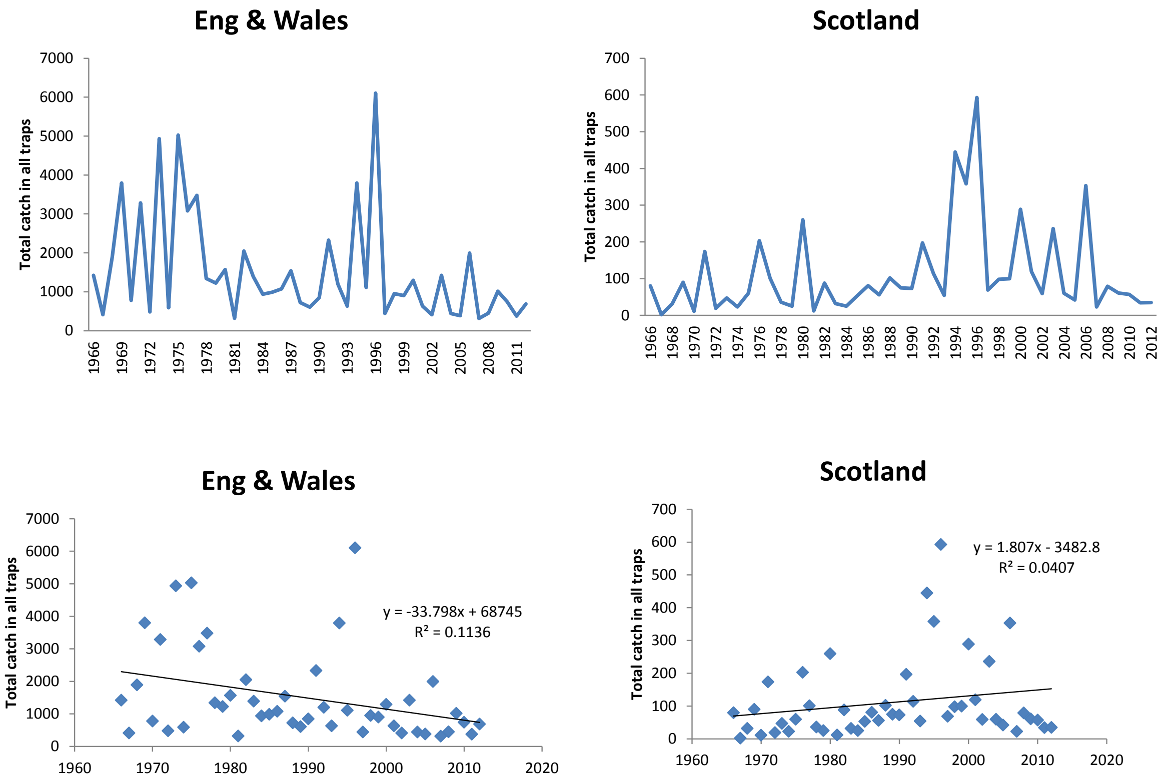


Figure 3.1. Summary of the captures of silver Y moth made by the network of light traps run by the Rothamsted Insect Survey.

South Lincolnshire

Figure 3.2 shows the mean numbers of silver Y moths captured per week in pheromone traps at JEPCO (data provided by Ben Dodson) between 2004 and 2016. The data are also summarised in Table 3.1. Moths were relatively abundant in 2013 and 2015 and most active between mid-June and mid-August.

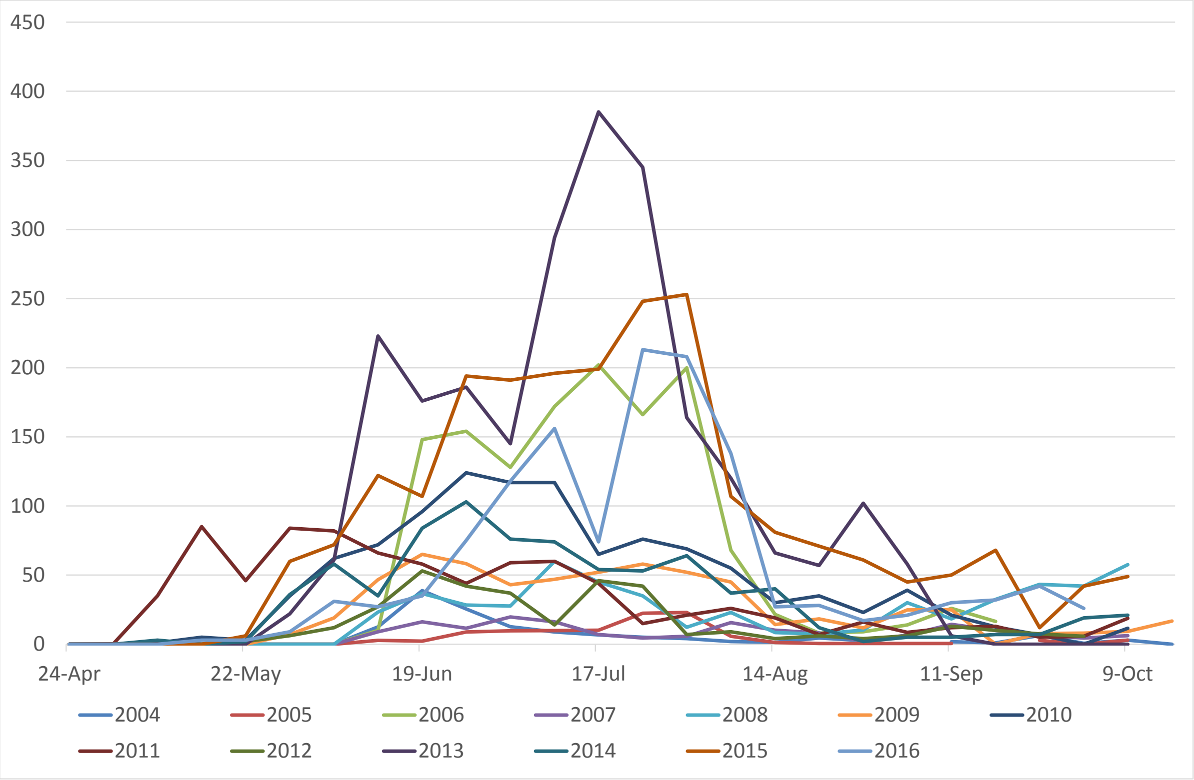


Figure 3.2. Distribution of captures of male silver Y moths captured by pheromone traps in south Lincolnshire (JEPCO) each year from 2004 to 2016. Data provided by Ben Dodson.

Table 3.1. Distribution of captures of male silver Y moths captured by pheromone traps in south Lincolnshire (JEPCO) each year from 2004 to 2016. Data provided by Ben Dodson. Highlights show average captures above an arbitrary threshold of 20 per week to indicate how the pressure varies in time (and numbers) between years.

Week beginning	2004	2005	2006	2007	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
24-Apr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1-May	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0
8-May	0.0	0.0	0.0	0.0	0.0	0.0	1.0	35.0	0.0	0.0	3.0	0.0	0.0
15-May	0.0	0.0	0.0	0.0	0.0	0.0	5.0	85.0	0.0	0.0	0.0	0.0	3.0
22-May	0.0	0.0	0.0	0.0	0.0	0.0	3.0	46.0	2.0	0.0	2.0	6.0	3.0
29-May	0.0	0.0	0.0	0.0	0.0	7.0	35.0	84.0	6.2	22.0	36.0	60.0	9.0
5-Jun	0.0	0.0	0.0	0.0	0.0	19.0	62.0	82.0	12.0	61.0	58.0	72.0	31.0
12-Jun	12.6	2.8	10.0	9.0	23.3	46.7	72.0	66.0	27.0	223.0	35.0	122.0	27.0
19-Jun	38.7	2.2	148.0	16.2	36.7	65.0	96.0	58.0	53.0	176.0	84.0	107.0	35.0
26-Jun	25.5	8.9	154.0	11.5	28.3	58.3	124.0	44.0	42.0	186.0	103.0	194.0	75.0
3-Jul	12.6	9.7	128.0	19.7	27.7	43.0	117.0	59.0	37.0	145.0	76.0	191.0	118.0
10-Jul	8.8	9.9	172.0	16.2	60.0	47.0	117.0	60.0	14.0	294.0	74.0	196.0	156.0
17-Jul	6.8	10.2	202.0	7.0	45.0	52.0	65.0	44.0	46.0	385.0	54.0	199.0	74.0
24-Jul	5.0	22.4	166.0	4.5	35.0	58.0	76.0	15.0	42.0	345.0	53.0	248.0	213.0
31-Jul	4.0	23.0	200.0	5.8	12.3	52.0	69.0	21.0	7.0	164.0	64.0	253.0	208.0
7-Aug	1.9	5.7	68.0	15.6	23.0	45.0	55.0	26.0	9.0	120.0	37.0	107.0	138.0
14-Aug	1.4	1.2	21.5	10.1	8.4	14.2	30.0	19.0	4.0	66.0	40.0	81.0	27.0
21-Aug	4.4	0.6	8.0	8.2	7.3	18.3	35.0	7.0	6.0	57.0	12.0	71.0	28.0
28-Aug	2.7	0.5	9.0	2.4	10.3	11.8	23.0	16.0	4.0	102.0	2.0	61.0	17.0
4-Sep		0.5	14.0	6.6	30.0	24.8	39.0	8.6	6.0	58.0	5.0	45.0	21.0
11-Sep	1.8	0.5	26.0	14.4	18.3	25.0	21.0	12.0	13.0	6.0	5.0	50.0	30.0
18-Sep	1.0		16.5	10.0	32.5	19..4	12.5	13.0	10.0	0.0	7.0	68.0	32.0
25-Sep	6.4	2.8		6.3	43.3	7.7	6.8	5.0	7.4	0.0	7.0	12.0	42.0
2-Oct	0.7	0.0	14.5	4.5	42.0	8.0	0.0	5.8	5.8	0.0	19.0	42.0	26.0
9-Oct	3.0	2.9		6.1	57.5	9.3	11.5	18.8		0.0	21.0	49.0	
16-Oct	0.0					16.7							
Total	**137**	**104**	**1358**	**174**	**541**	**629**	**1076**	**830**	**353**	**2410**	**797**	**2234**	**1313**

Wellesbourne

Figure 3.3 shows the total numbers of moths captured by 2 pheromone traps at Wellesbourne each year from 2011 to 2016 and Figure 3.4 shows the distribution of captures of moths. In 2001 in particular, male moths were captured very late in the year (October/November) and were obviously still responding to pheromones at this stage.

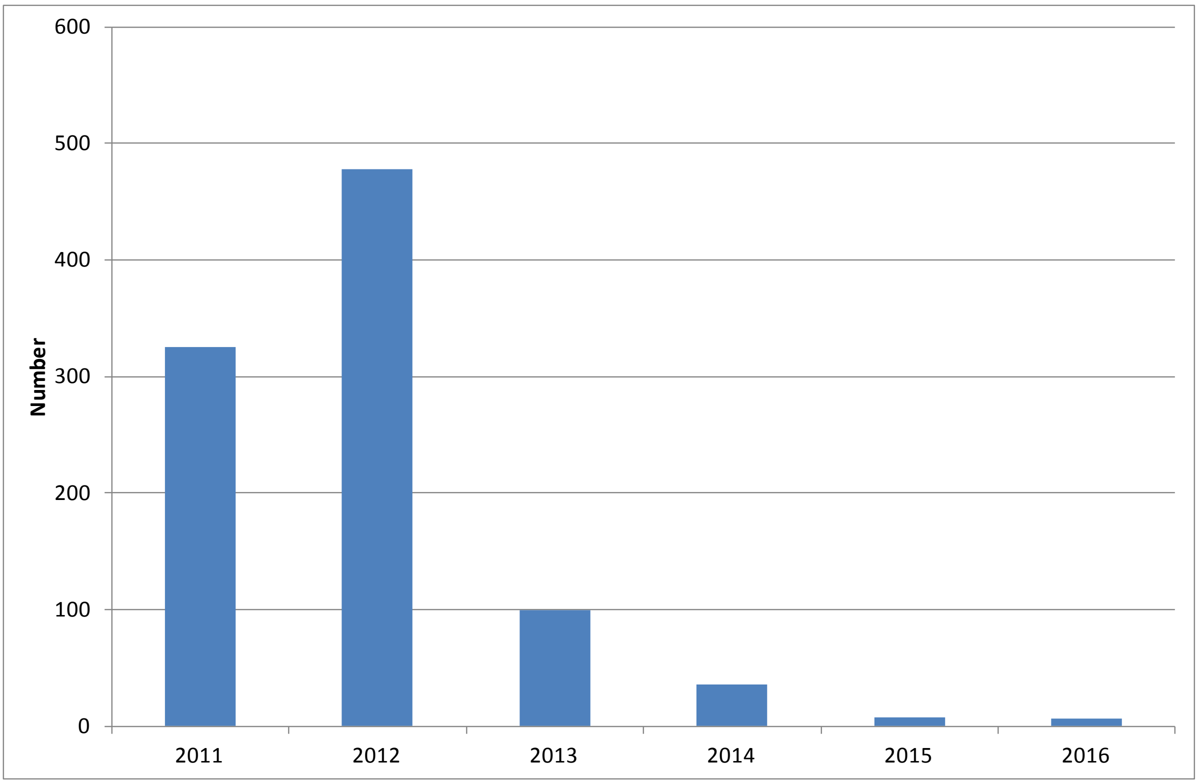


Figure 3.3. Total numbers of male silver Y moths captured by 2 pheromone traps at Wellesbourne each year from 2011 to 2016.

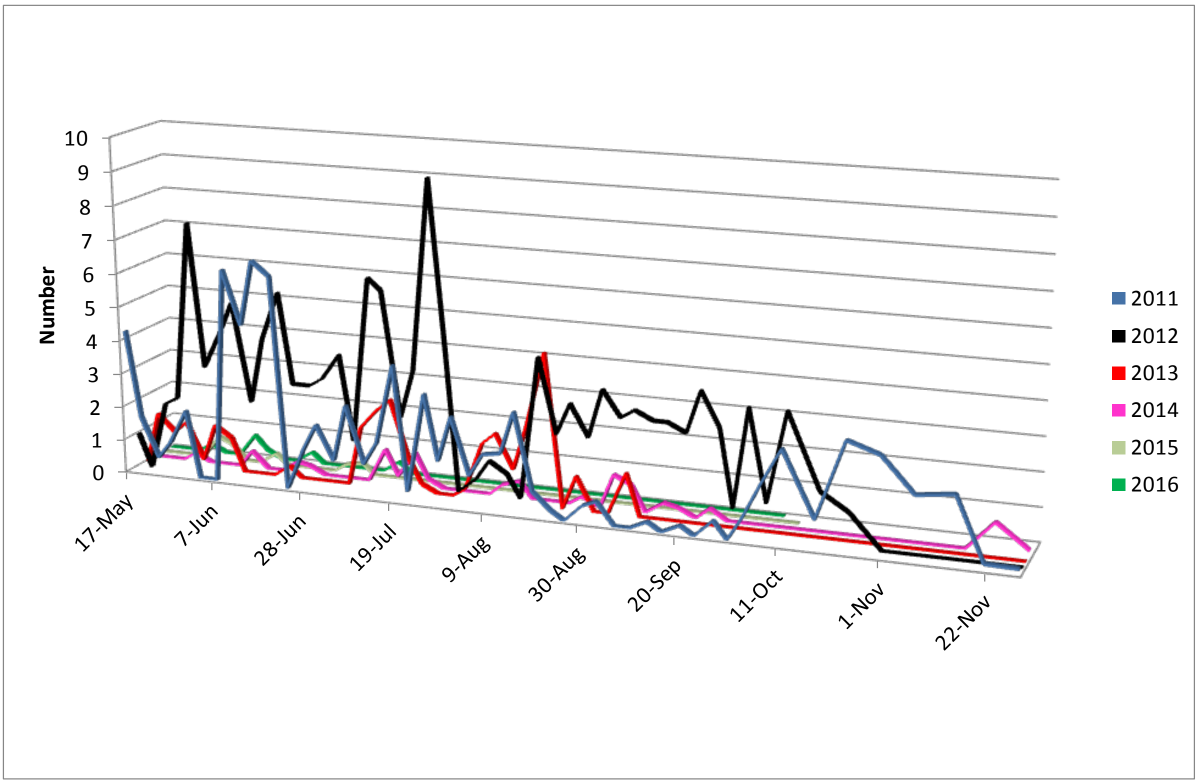


Figure 3.4. Distribution of captures of male silver Y moths (numbers per day) at Warwick Crop Centre, Wellesbourne by two pheromone traps each year from 2011 to 2016.

Cambridgeshire and Norfolk

Figures 3.5 and 3.6 show the mean numbers of silver Y moths captured per week in pheromone traps at G's (data provided by David Norman) in 2013 and 2014. Traps were deployed for different periods depending on the cropping sequence.

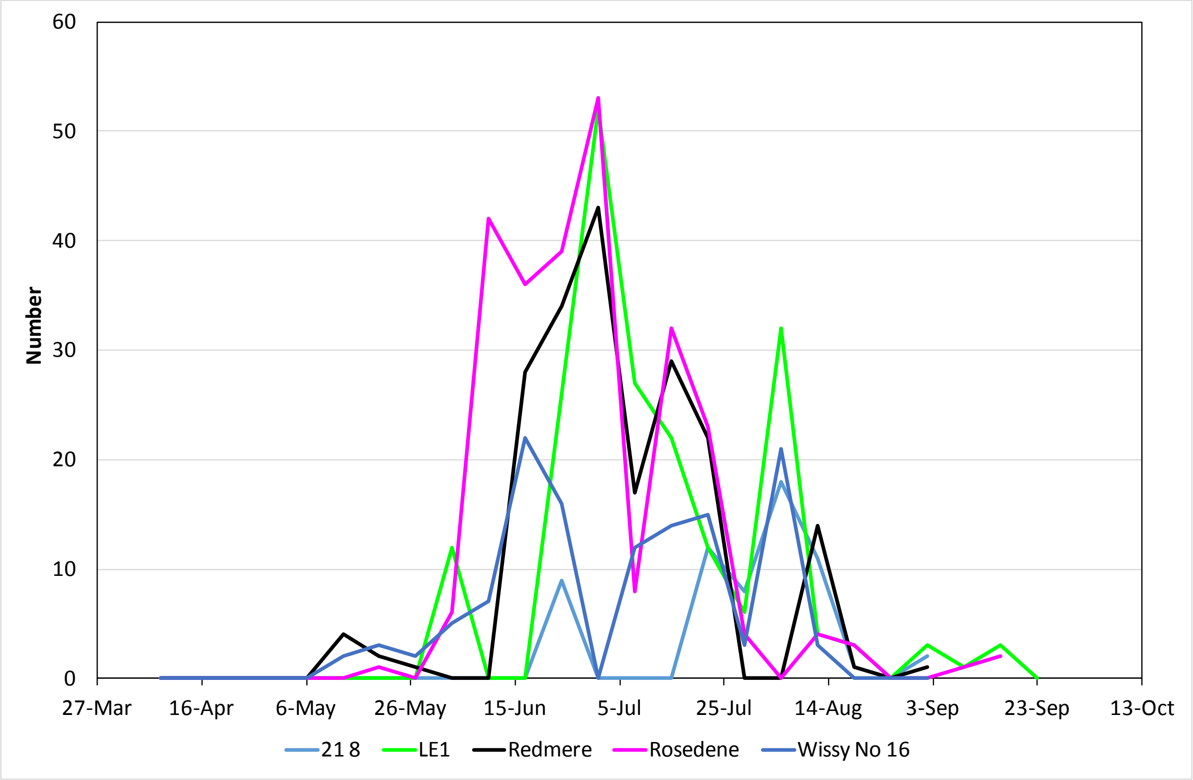


Figure 3.5. Numbers of male silver Y moths captured by pheromone traps near G's crops in 2013. Data provided by David Norman.

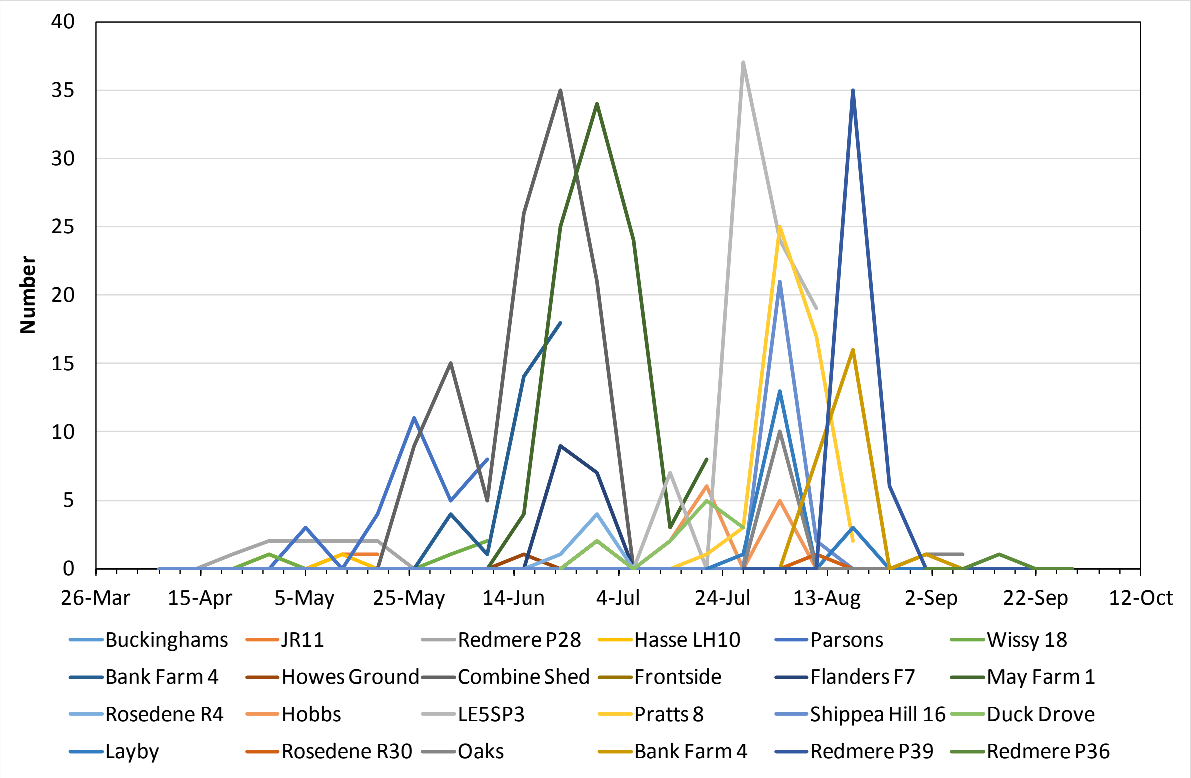


Figure 3.6. Numbers of male silver Y moths captured by pheromone traps near G's crops in 2014. Data provided by David Norman.

Tables 3.2 and 3.3 summarise the data from the traps run in 2013 and 2014 and indicate how much moth numbers vary between locations.

Table 3.2. Mean numbers of male silver Y moths captured by pheromone traps near G's crops in 2013 per week. The table also shows the number of traps running each week and the maximum and minimum numbers of moths captured per trap. Data provided by David Norman.

Week	Mean number of moths per trap per week	Number of traps running	Maximum number captured per trap	Minimum number captured per trap
08-Apr-13	0	5	0	0
15-Apr-13	0	5	0	0
22-Apr-13	0	5	0	0
29-Apr-13	0	5	0	0
06-May-13	0	5	0	0
13-May-13	1.2	5	4	0
20-May-13	1.2	5	3	0
27-May-13	0.6	5	2	0
03-Jun-13	4.6	5	12	0
10-Jun-13	9.8	5	42	0
17-Jun-13	17.2	5	36	0
24-Jun-13	24.8	5	39	9
01-Jul-13	29.6	5	53	0
08-Jul-13	12.8	5	27	0
15-Jul-13	19.4	5	32	0
22-Jul-13	16.8	5	23	12
29-Jul-13	4.2	5	8	0
05-Aug-13	14.2	5	32	0
12-Aug-13	7.2	5	14	3
19-Aug-13	1.6	5	3	0
26-Aug-13	0	5	0	0
02-Sep-13	1.2	5	3	0
09-Sep-13	1	3	1	1
16-Sep-13	2.5	2	3	2
23-Sep-13	0	1	0	0

Table 3.3. Mean numbers of male silver Y moths captured by pheromone traps near G's crops in 2014 per week. The table also shows the number of traps running each week and the maximum and minimum numbers of moths captured per trap. Data provided by David Norman.

Week	Mean number of moths per trap per week	Number of traps running	Maximum number captured per trap	Minimum number captured per trap
7-Apr-14	0	17	0	0
14-Apr-14	0	17	0	0
21-Apr-14	0.06	17	1	0
28-Apr-14	0.24	17	2	0
5-May-14	0.29	17	3	0
12-May-14	0.25	16	2	0
19-May-14	0.44	16	4	0
26-May-14	1.33	15	11	0
2-Jun-14	1.79	14	15	0
9-Jun-14	1.23	13	8	0
16-Jun-14	4.09	11	26	0
23-Jun-14	7.33	12	35	0
30-Jun-14	6.36	11	34	0
7-Jul-14	2.40	10	24	0
14-Jul-14	1.75	8	7	0
21-Jul-14	2.50	8	8	0
28-Jul-14	4.00	11	37	0
4-Aug-14	9.80	10	25	0
11-Aug-14	5.22	10	19	0
18-Aug-14	8.00	7	35	0
25-Aug-14	1.50	4	6	0
1-Sep-14	0.40	4	1	0
8-Sep-14	0.25	4	1	0
15-Sep-14	0.33	3	1	0
22-Sep-14	0	2	0	0
29-Sep-14	0	2	0	0

Diamond-back moth

Kirton

Data on diamond-back populations in commercial brassica crops were collected at HRI Kirton 20 years ago and there was a particularly large migration in 1996. Figure 3.7 shows the numbers of moths captured in pheromone traps and the numbers of eggs, larvae and pupae found in a Brussels sprout crop at Kirton in 1996. This shows clearly that eggs were being laid on brassica plants during the same period that male moths were captured in pheromone traps.

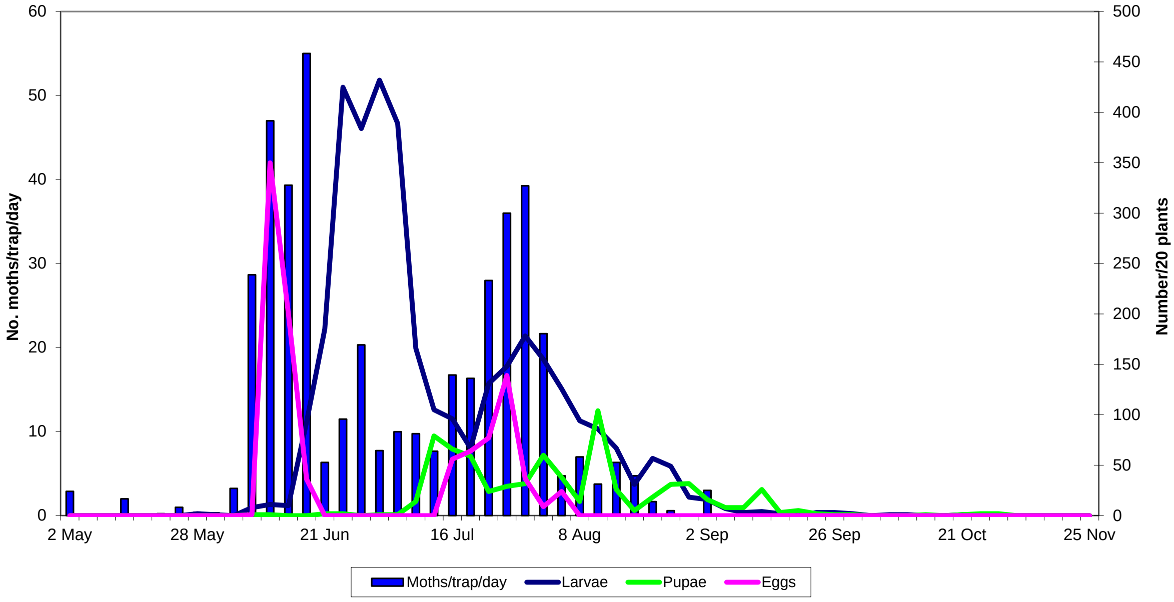


Figure 3.7. Numbers of diamond-back moth eggs, larvae and pupae found on 20 Brussels sprout plants at HRI Kirton in 1996 and numbers of male moths per trap per day captured in pheromone traps.

Wellesbourne

Figure 3.8 shows the total numbers of male diamond-back moths captured by 2 pheromone traps at Wellesbourne each year from 2006 to 2016, highlighting the large numbers captured in 2016, and Figure 3.9 shows the distribution of captures of male diamond-back moths.

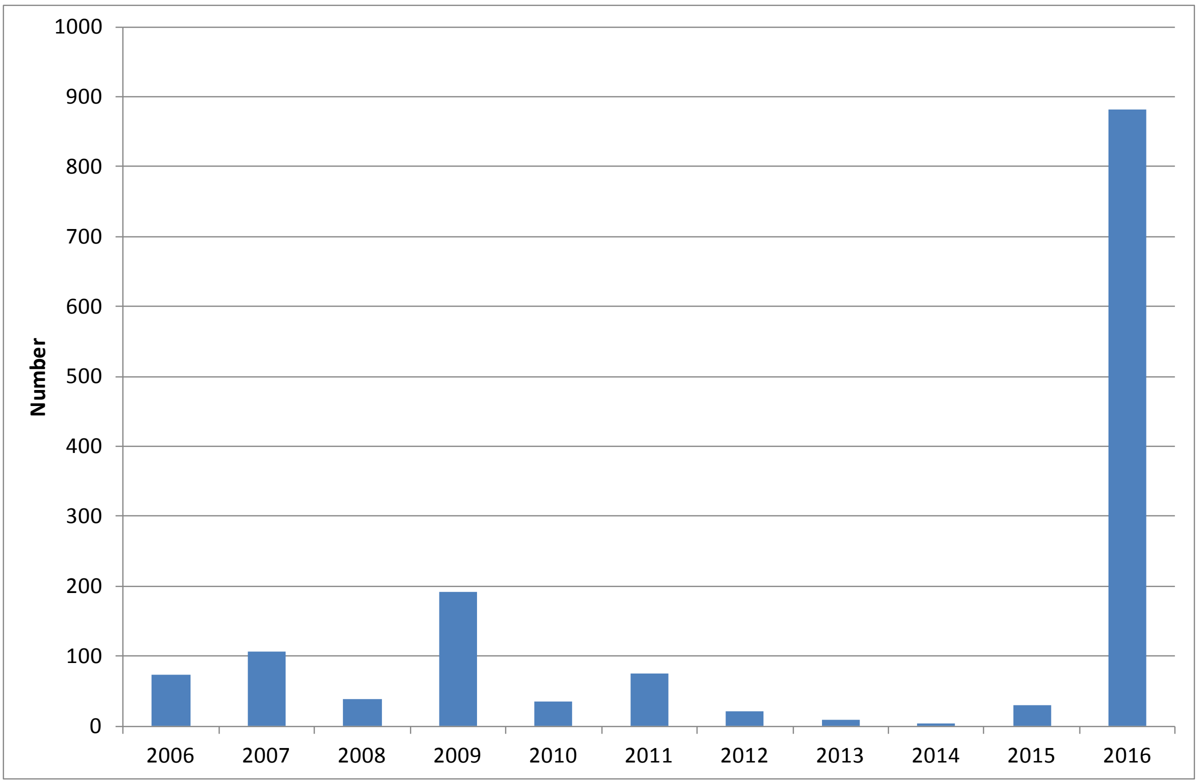


Figure 3.8. Total numbers of male diamond-back moths captured by 2 pheromone traps at Wellesbourne each year from 2006 to 2016.

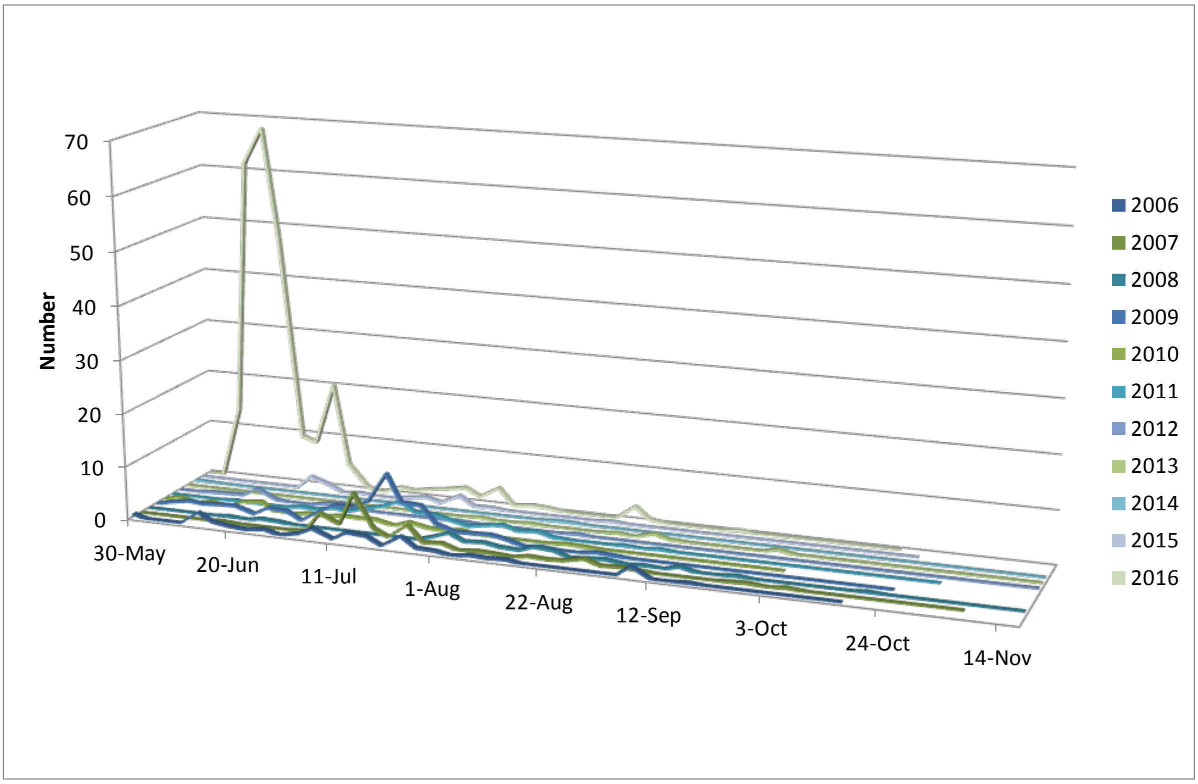


Figure 3.9. Distribution of captures of male diamond-back moths captured by 2 pheromone traps at Wellesbourne each year from 2006 to 2016

Turnip moth

Wellesbourne

Figure 3.10 shows the total numbers of male turnip moths captured by 2 pheromone traps at Wellesbourne each year from 2006 to 2016 (first and second generations) and Figure 3.11 shows the distribution of captures of male turnip moths.

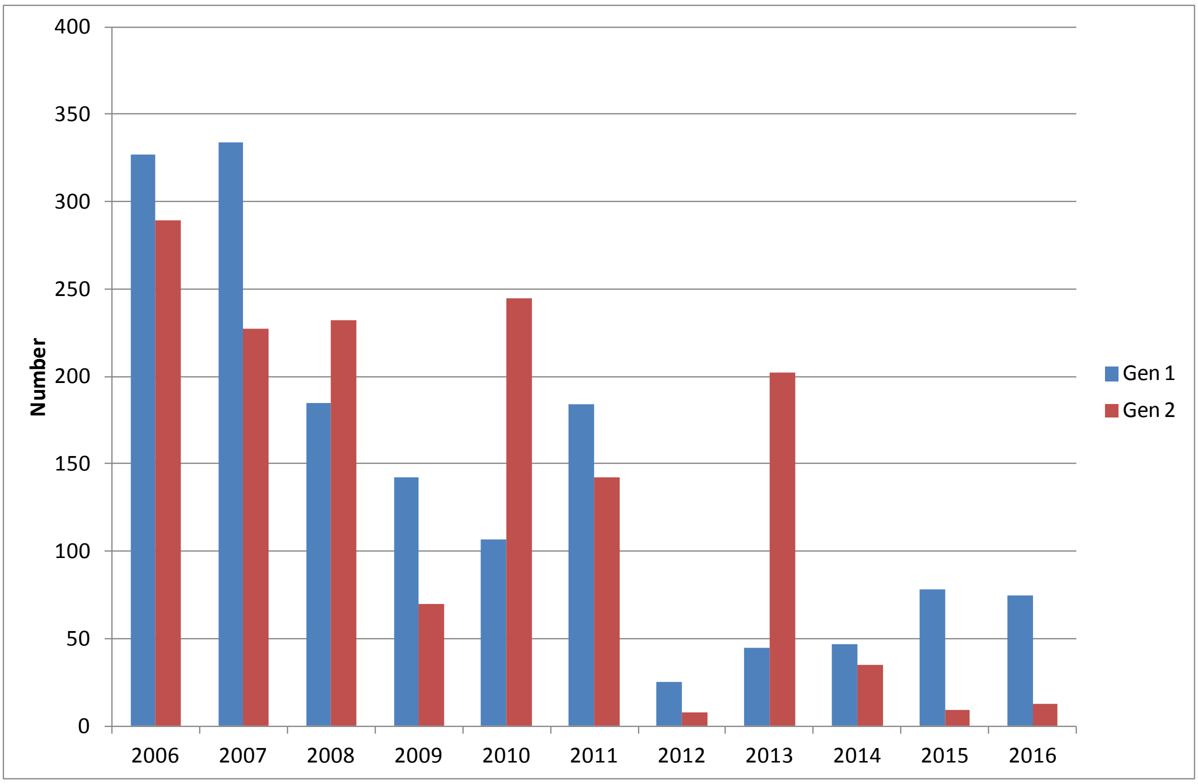


Figure 3.10. Total numbers of male turnip moths captured by 2 pheromone traps at Wellesbourne each year from 2006 to 2016 (first and second generations).

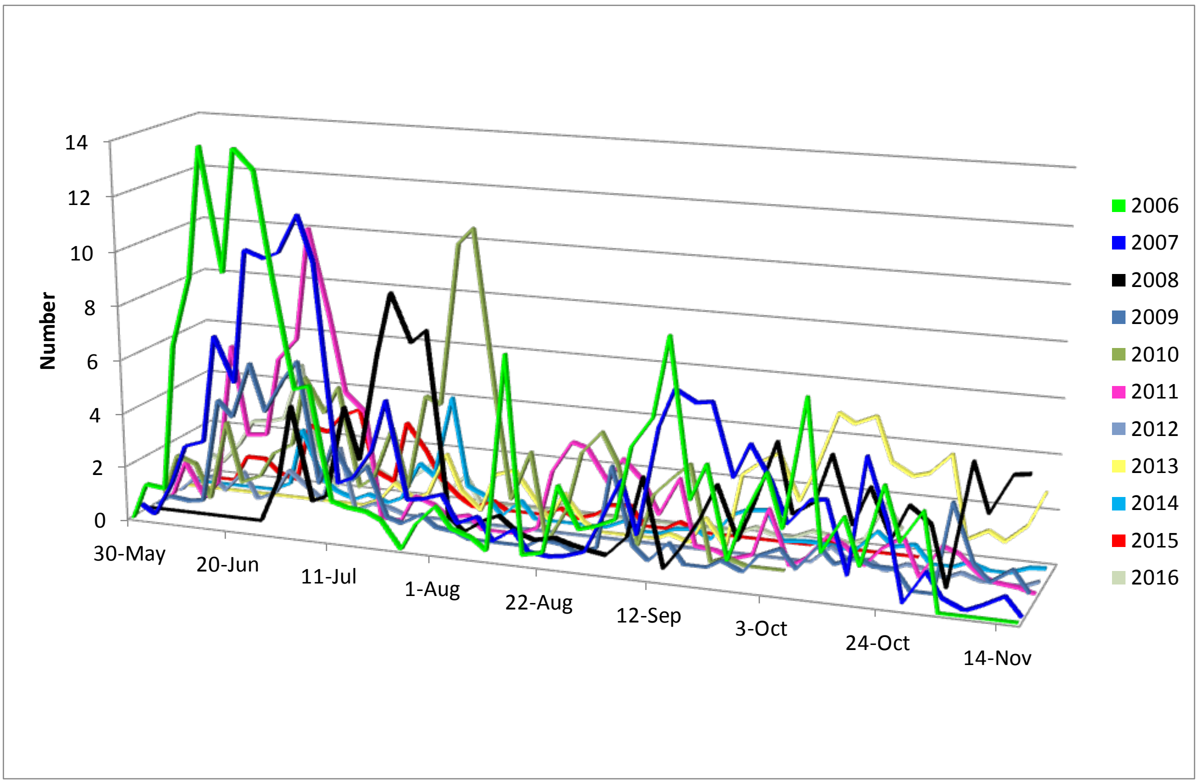


Figure 3.11. Distribution of captures of male turnip moths by 2 pheromone traps at Wellesbourne each year from 2006 to 2016

Cambridgeshire and Norfolk

Figure 3.12 shows the numbers of male turnip moths captured by pheromone traps at G's in 2014. This shows the timing of the two generations very clearly.

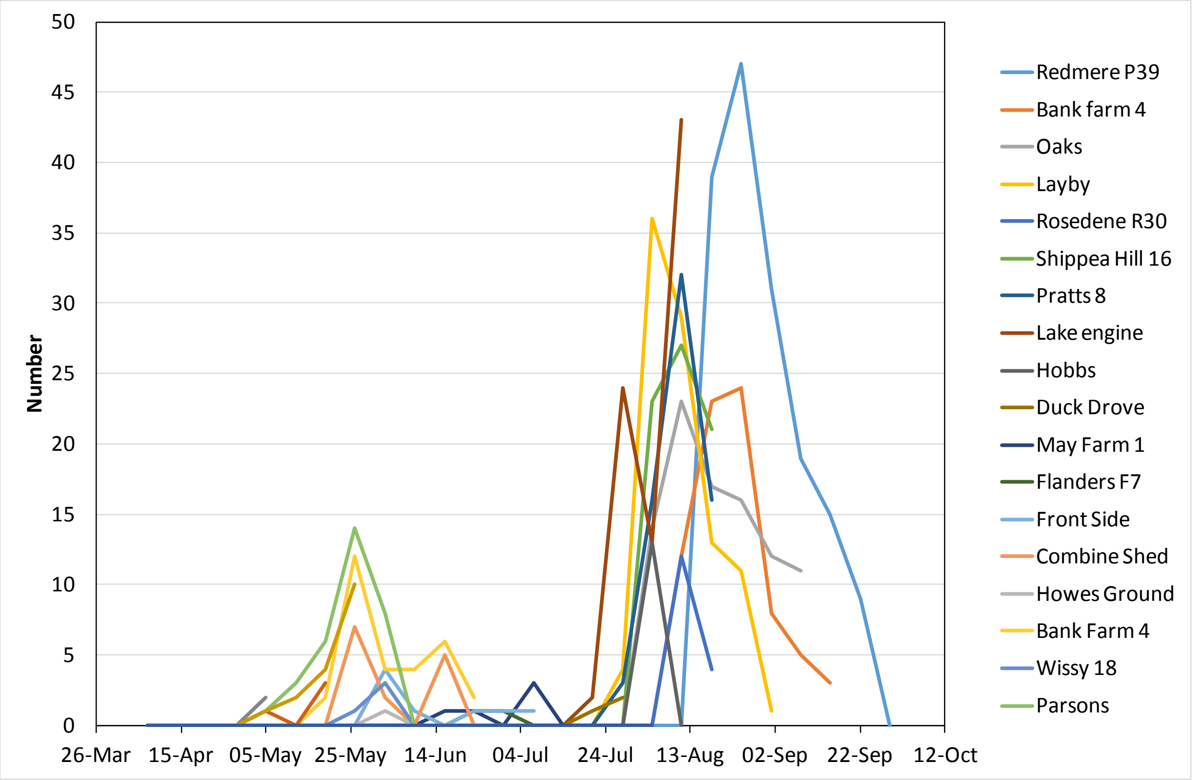


Figure 3.12. The numbers of male turnip moths captured by pheromone traps at G's in 2014. Data provided by David Norman.

Monitoring activity of adult moths in 2015 and 2016

A network of pheromone traps was established in England and Scotland in 2015 and 2016 to monitor silver Y moth, diamond-back moth and turnip moth. The traps were supplied by Trapview (www.trapview.com) and the network was supported and managed by Colin Carter of Landseer. A total of 30 traps were set up in May-June 2015 and consisted of 18 traps for silver Y moth, 10 traps for diamond-back moth and 2 traps for turnip moth plus an 'experimental' trap used for trap development. The traps were hosted by growers of salad and Brassica crops (Table 3.4).

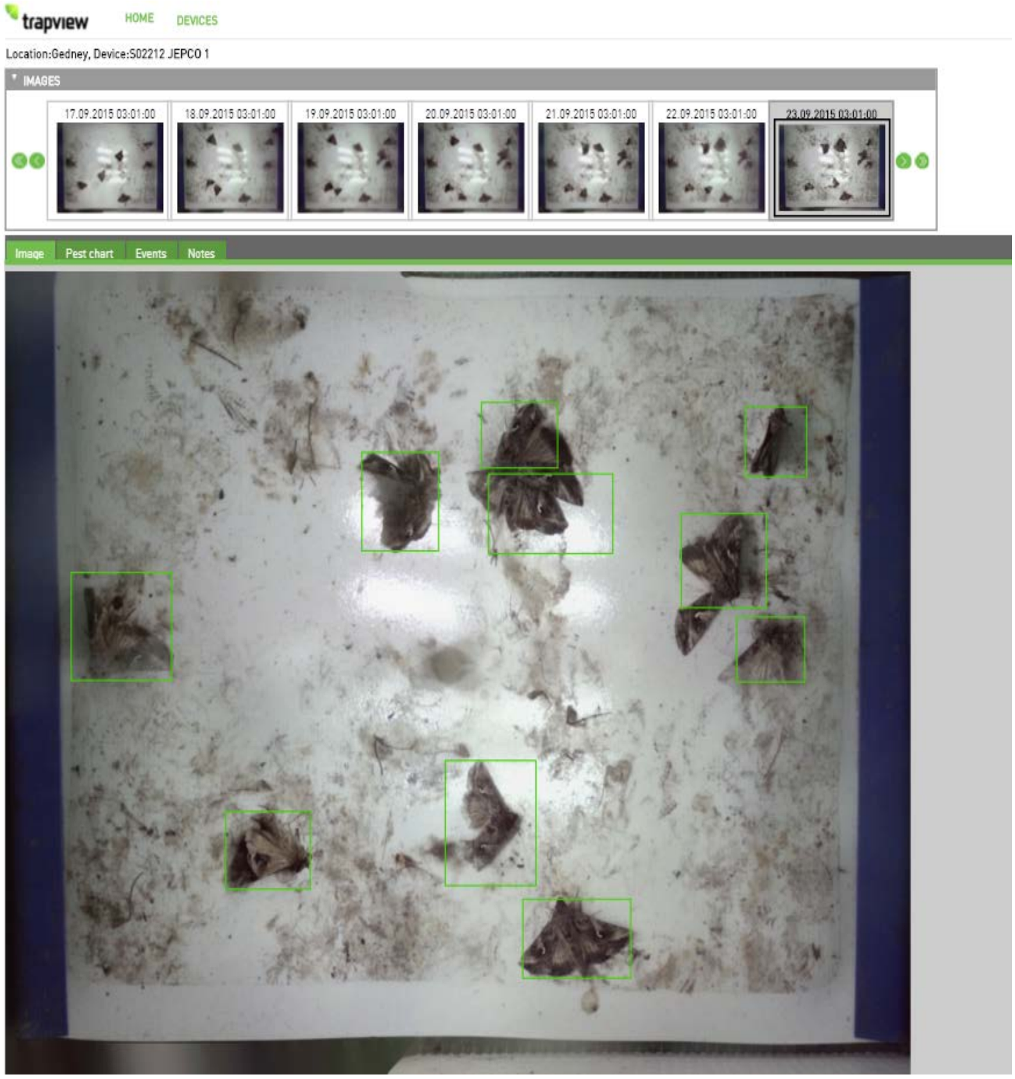
Table 3.4. Locations of Trapview traps in 2015.

Host	Location	Crop	Pest moth
Warwick Crop Centre	Warwick	Salads	Diamond-back moth
KS Coles	South West	Swede	Diamond-back moth
KS Coles	South West	Swede	Diamond-back moth
Polybell Organic	Doncaster	Brassica	Diamond-back moth
Saul Farms	Leverton, Lincs	Brassica	Diamond-back moth
Angflor	Frating, Essex	Brassica	Diamond-back moth
Kettle Produce	Scotland	Brassica	Diamond-back moth
Kettle Produce	Scotland	Brassica	Diamond-back moth
Philpott	Kent	Brassica	Diamond-back moth
Philpott	Kent	Brassica	Diamond-back moth
G's	Norfolk	Salads	Silver Y moth
G's	Norfolk	Salads	Silver Y moth
G's	Barway - Ely	Salads	Silver Y moth
G's	Cambs	Salads	Silver Y moth
G's	Norfolk	Salads	Silver Y moth
G's	Cambs	Salads	Silver Y moth
G's	TLC - Sussex	Salads	Silver Y moth
G's	TLC - Sussex	Salads	Silver Y moth
Intercrop	Sandwich - Kent	Salads	Silver Y moth
Intercrop	Sandwich - Kent	Salads	Silver Y moth
Intercrop	Worth - Kent	Salads	Silver Y moth
WCC	Warwick	Salads	Silver Y moth
JEPCO	Gedney - East	Salads	Silver Y moth
JEPCO	Gedney - East	Salads	Silver Y moth
KS Coles	South West	Peas	Silver Y moth
KS Coles	South West	Peas	Silver Y moth
Anglia Salads	Essex	Salads	Silver Y moth
Anglia Salads	Essex	Salads	Silver Y moth
G's	Barway - Ely	Turnip	Turnip moth
G's	Norfolk	Turnip	Turnip moth

One of the Trapview traps is shown in Figures 3.13 and 3.14. Each trap contained a pheromone lure for the appropriate species, a sticky base to capture the moths and a small camera which photographed the sticky base once each day. The camera was powered by a solar cell. The image was downloaded onto the website managed by Trapview and the images of the captures by all the traps (Figure 3.15) were visible to all the trap hosts. Generally there were two ‘replicate’ traps in each area. ‘Ordinary’ pheromone traps were run in parallel to the ‘Trapview traps’ with the aim to have at least one at each site. The lures were replaced at the recommended intervals and the sticky bases were replaced as and when necessary. The data from the Trapview traps were downloaded from the Trapview site and checked and corrected using the images. Data from the other traps were sent to Warwick Crop Centre at the end of the season.

Figure 3.13. Trapview pheromone trap

Figure 3.14. Close up of ‘Trapview’ pheromone trap



Location:Gedney, Device:S02212 JEPCO 1

Figure 3.15. Image of silver Y moths captured in Trapview trap taken from Trapview website

In 2016 a similar network of traps was set up as shown in Table 3.5.

Table 3.5. Locations of Trapview traps in 2016.

Host	**Location**	**Crop**	**Pest moth**
Warwick Crop Centre	Warwick	Salads	Diamond-back moth
KS Coles	South West	Swede	Diamond-back moth
KS Coles	South West	Swede	Diamond-back moth
Polybell Organic	Doncaster	Brassica	Diamond-back moth
Saul Farms	Leverton, Lincs	Brassica	Diamond-back moth
Anglia Salads	Frating, Essex	Brassica	Diamond-back moth
Kettle Produce	Scotland	Brassica	Diamond-back moth
Kettle Produce	Scotland	Brassica	Diamond-back moth
Philpott	Kent	Brassica	Diamond-back moth
Philpott	Kent	Brassica	Diamond-back moth
KS Coles	South West	Peas	Pea moth
G's	Fliby - Wharton	Salads	Silver Y moth
G's - Norfolk	Southery - Wissy	Salads	Silver Y moth
G's - Cambs	Barway - Ely Hainey	Salads	Silver Y moth
G's	Walcott - Love	Salads	Silver Y moth
G's - Cambs	Shippea Hill - Redmere P36	Salads	Silver Y moth
G's - Cambs	Littleport - Plantation R.Run	Salads	Silver Y moth
G's	TLC - Sussex - Fishbourne	Salads	Silver Y moth
G's	TLC - Sussex Pagham	Salads	Silver Y moth
Intercrop	Sandwich - Kent	Salads	Silver Y moth
Intercrop	Sandwich - Kent	Salads	Silver Y moth
Intercrop	Worth - Kent	Salads	Silver Y moth
WCC	Warwick	Salads	Silver Y moth
JEPCO	Gedney - East	Salads	Silver Y moth
JEPCO	Gedney - East	Salads	Silver Y moth
KS Coles	South West	Peas	Silver Y moth
KS Coles	South West	Peas	Silver Y moth
Anglia Salads	Essex	Salads	Silver Y moth
Anglia Salads	Essex	Salads	Silver Y moth
G's - Norfolk	Norfolk - Wissy	Turnip	Turnip moth
G's - Cambs	Barway - Ely	Turnip	Turnip moth

Results

Silver Y moth 2015

Captures by all of the Trapview traps in 2015 are summarised by county in Figures 3.16 and 3.17. Not all of the traps were fully operational in May but the figures show that moths were captured between May and October with periods of more intense activity in mid-June and mid-July. There is no evidence that moths were captured earlier at sites that were further south or further east, for example.

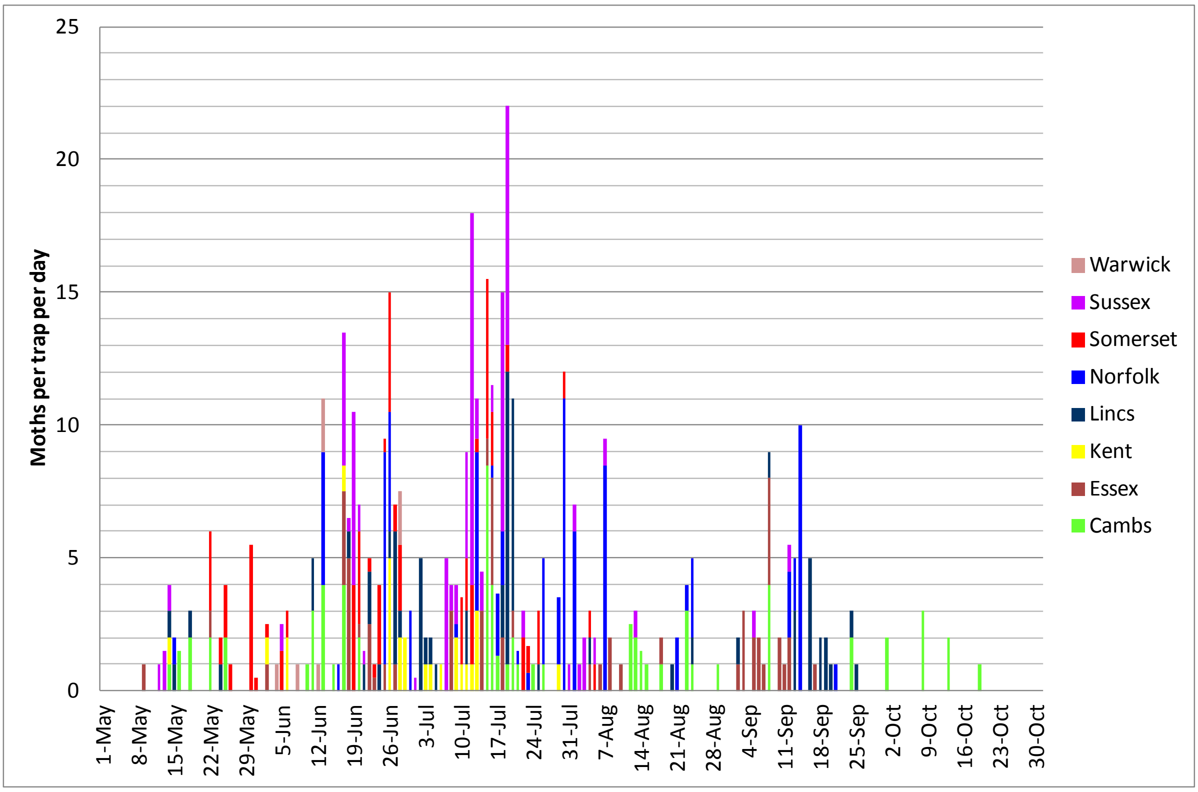


Figure 3.16. Captures of silver Y moths by Trapview traps in 2015 (moths per trap per day in each county).

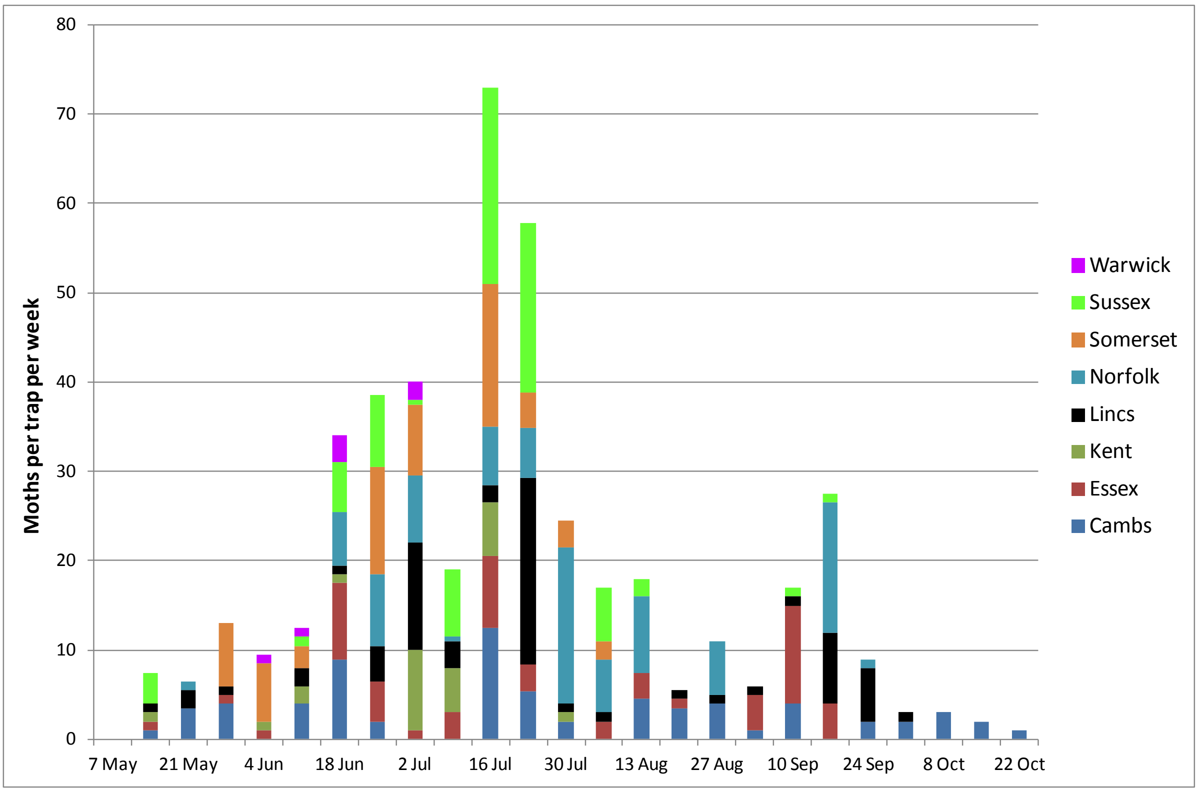


Figure 3.17. Captures of silver Y moths by Trapview traps in 2015 (moths per trap per week in each county).

A relatively large number of Funnel traps were deployed in crops of lettuce grown by G's. This was to obtain more detailed information on silver Y moth activity both from using traps and by monitoring crops. Some of the data collected is summarised below.

Figure 3.18 shows the numbers of moths captured per trap per week in the 'ordinary' funnel pheromone traps in 13 locations at G's in 2015. The main period of activity was between mid-June and mid-July and a maximum of 36 moths per trap was captured in one week. There was considerable variation between locations in the pattern of moth activity as represented by trap captures.

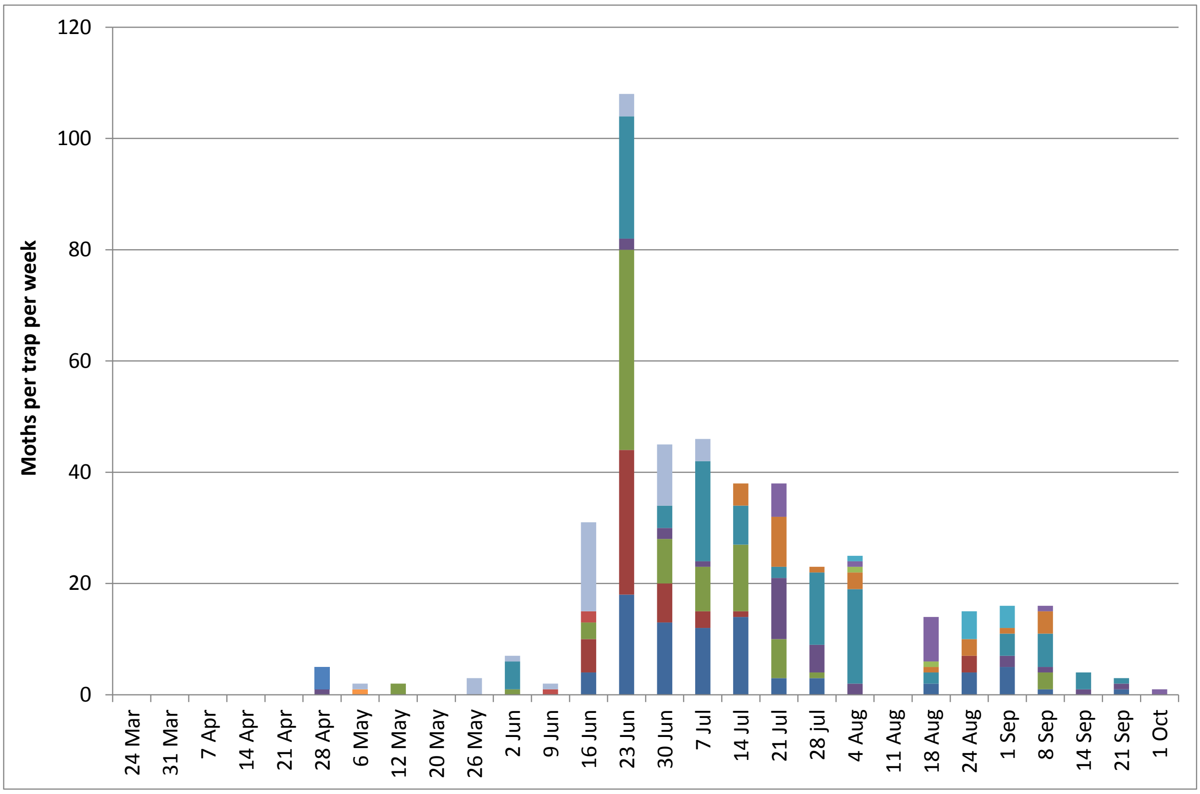


Figure 3.18. Captures of silver Y moths by 13 Funnel traps in G's crops in 2015. The different colours in the vertical bars represent the captures by traps in the 15 locations and are shown separately to illustrate the level of variation in numbers between individual traps.

Table 3.6 summarises captures at G's in 2015 in terms of the mean, maximum and minimum number of moths captured per week. As in 2013 and 2014, numbers varied considerably between locations.

Table 3.6. Captures of male silver Y moths at G's in 2015 in terms of the mean, maximum and minimum number of moths captured per week.

Week	Mean number of moths per trap per week	Number of traps running	Maximum number captured per trap	Minimum number captured per trap
24-Mar-15	0	4	0	0
31-Mar-15	0	6	0	0
7-Apr-15	0	7	0	0
14-Apr-15	0	7	0	0
21-Apr-15	0	7	0	0
28-Apr-15	0.63	8	4	0
6-May-15	0.25	8	1	0
12-May-15	0.29	7	2	0
20-May-15	0	9	0	0
26-May-15	0.38	8	3	0
2-Jun-15	0.88	8	5	0
9-Jun-15	0.25	8	1	0
16-Jun-15	3.88	8	16	0
23-Jun-15	13.50	8	36	0
30-Jun-15	5.63	8	13	0
7-Jul-15	5.11	8	18	0
14-Jul-15	4.22	9	14	0
21-Jul-15	4.22	10	11	0
28-Jul-15	2.67	10	13	0
4-Aug-15	2.67	10	17	0
11-Aug-15	0.00	10	0	0
18-Aug-15	2.11	10	8	0
24-Aug-15	1.56	10	4	0
1-Sep-15	1.33	10	5	0
8-Sep-15	1.78	10	6	0
14-Sep-15	0.44	10	3	0
21-Sep-15	0.43	7	1	0
1-Oct-15	0.14	7	1	0

Figures 3.19 and 3.20 compare the captures of silver Y moths at G's by Trapview traps with captures by funnel pheromone traps. The data are compared for the crops within a county – so either the traps in crops in Cambridgeshire or those in Norfolk. There were 3 Trapview traps and 4 Funnel traps in each county. Overall the patterns of activity were similar, but not identical. The differences in the pattern of captures may be simply a reflection of background variation between traps – as the capture of moths by the traps is essentially a random process – or also a reflection of the effect of the surrounding vegetation etc on the local silver Y population.

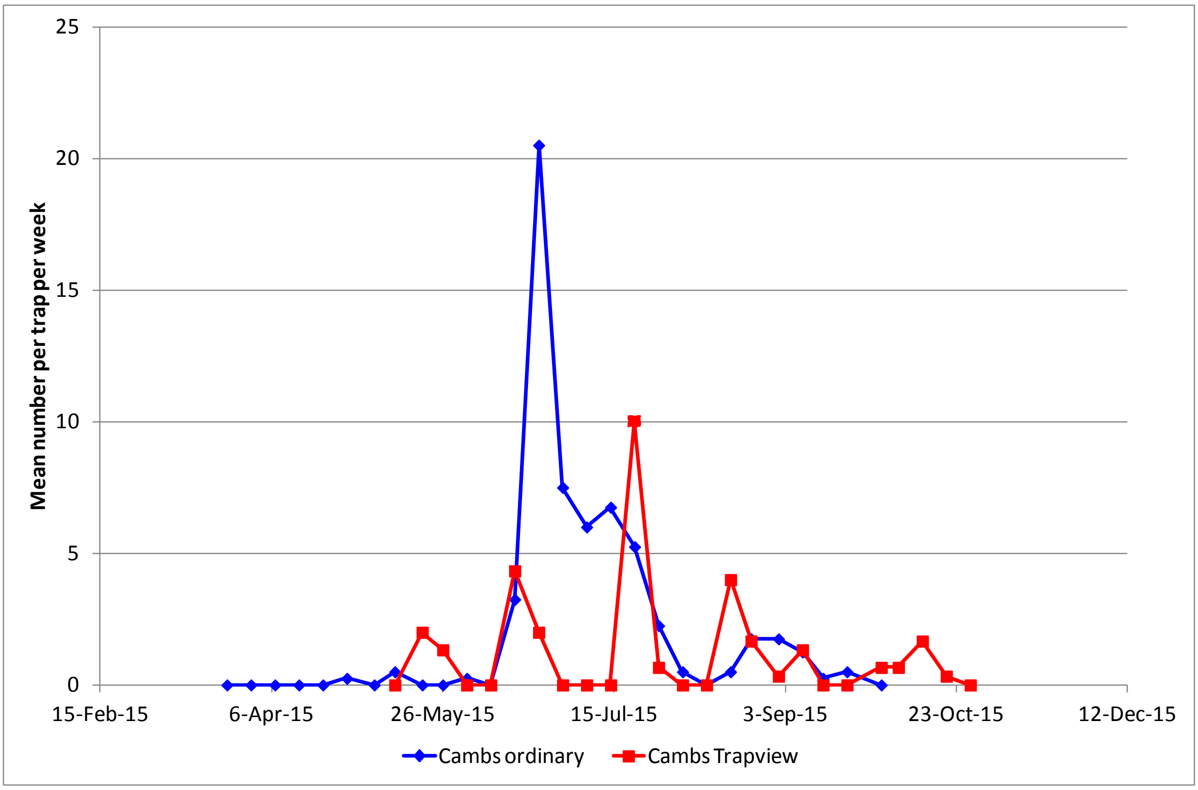


Figure 3.19. Captures of silver Y moths by Trapview traps and Funnel traps in G's crops in Cambridgeshire 2015.

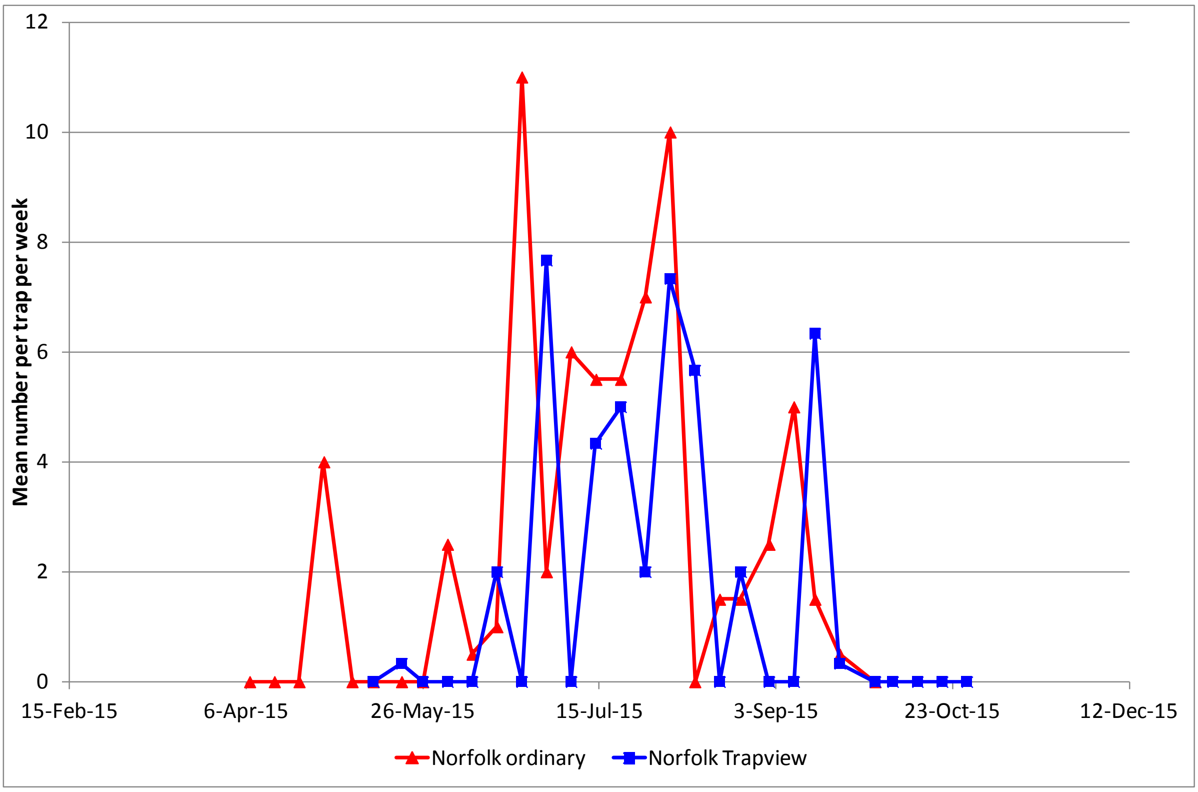


Figure 3.20. Captures of silver Y moths by Trapview traps and Funnel traps in G's crops in Norfolk 2015.

Figure 3.21 shows the captures of silver Y moths by the Trapview and funnel traps in Essex. Again the pattern of captures was similar between the two trap types, but not identical.

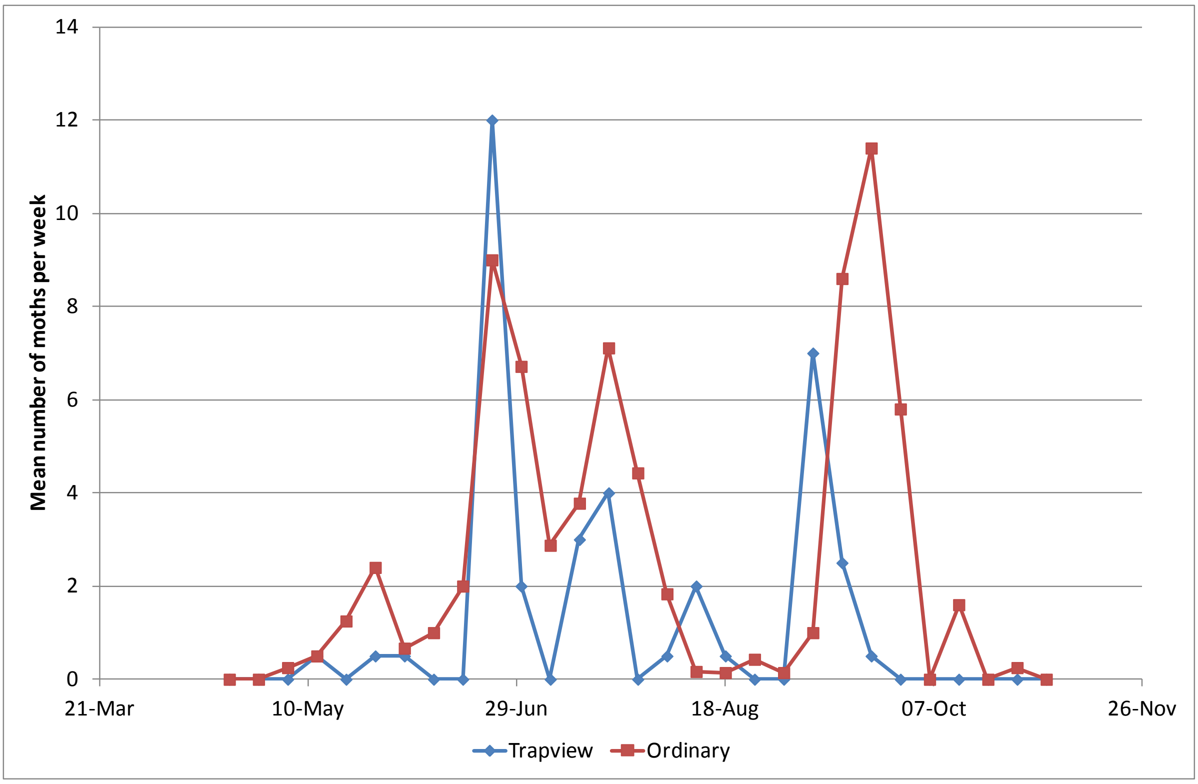


Figure 3.21. Captures of silver Y moths by Trapview traps and Funnel traps in Essex in 2015. Data supplied by Andrew Poole.

Figures 3.22 and 3.23 show the captures of silver Y moths by Trapview and funnel traps in Lincolnshire at two locations. Again the pattern of captures was similar between the two trap types but not identical. Captures by the Trapview traps were considerably lower than by the funnel traps.

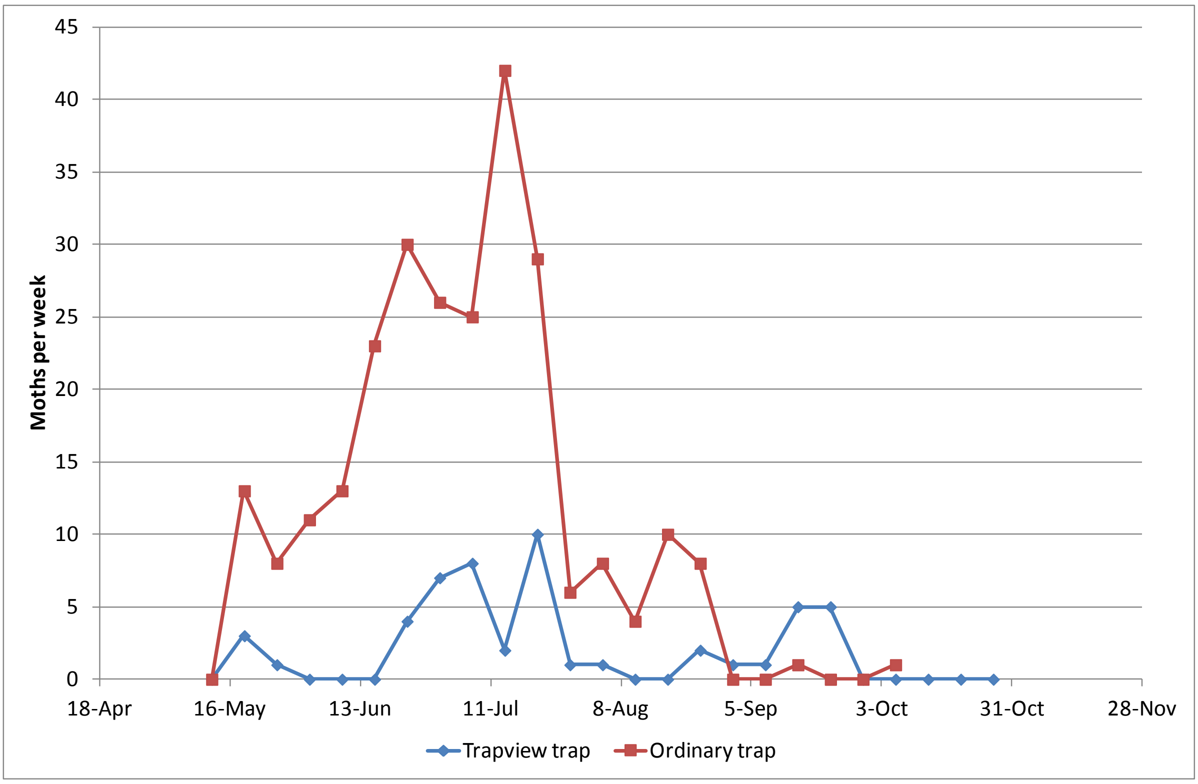


Figure 3.22. Captures of silver Y moths by Trapview traps and Funnel traps in Lincolnshire in 2015 – location 1. Data supplied by Ben Dodson.

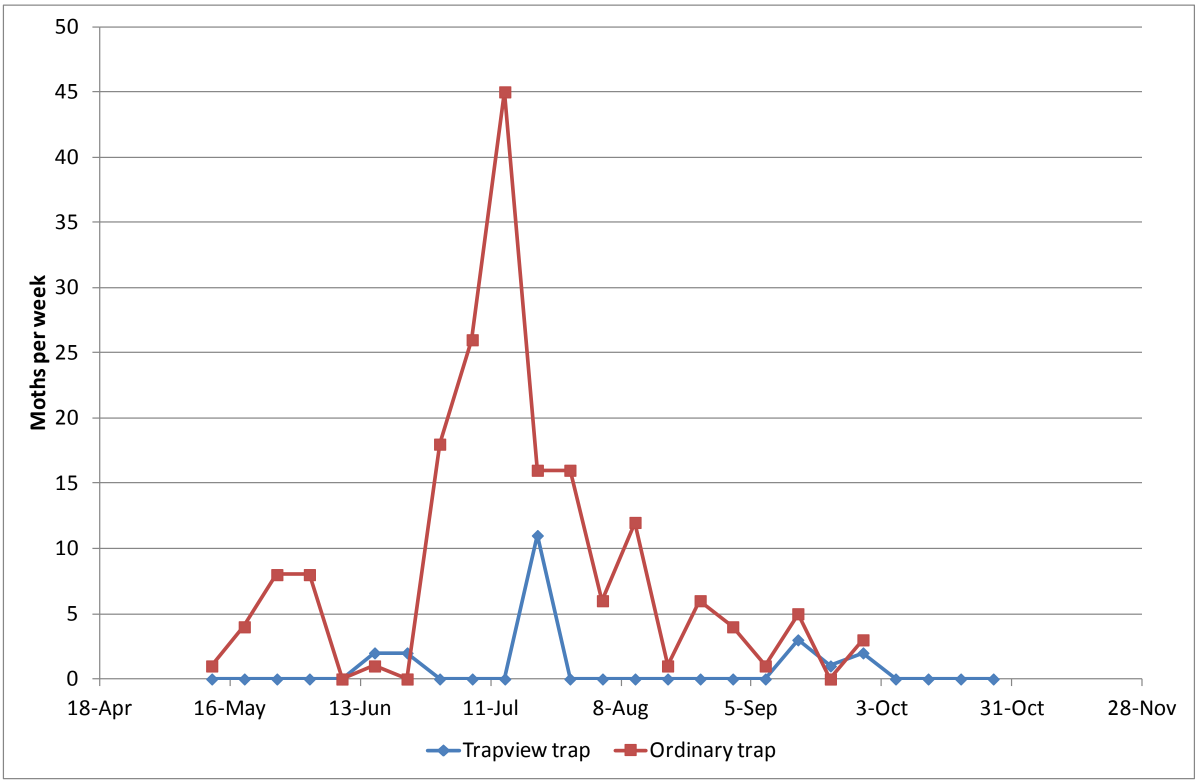


Figure 3.23. Captures of silver Y moths by Trapview traps and Funnel traps in Lincolnshire in 2015 – location 2. Data supplied by Ben Dodson.

Data from Funnel pheromone traps in 2015

No Trapview traps were used to monitor silver Y moth in Scotland. However, funnel pheromone traps were run at 4 locations and the captures are summarised in Figure 3.24. Overall, captures were low and nothing was captured in one of the traps. However, moths were present from mid-June until late August.

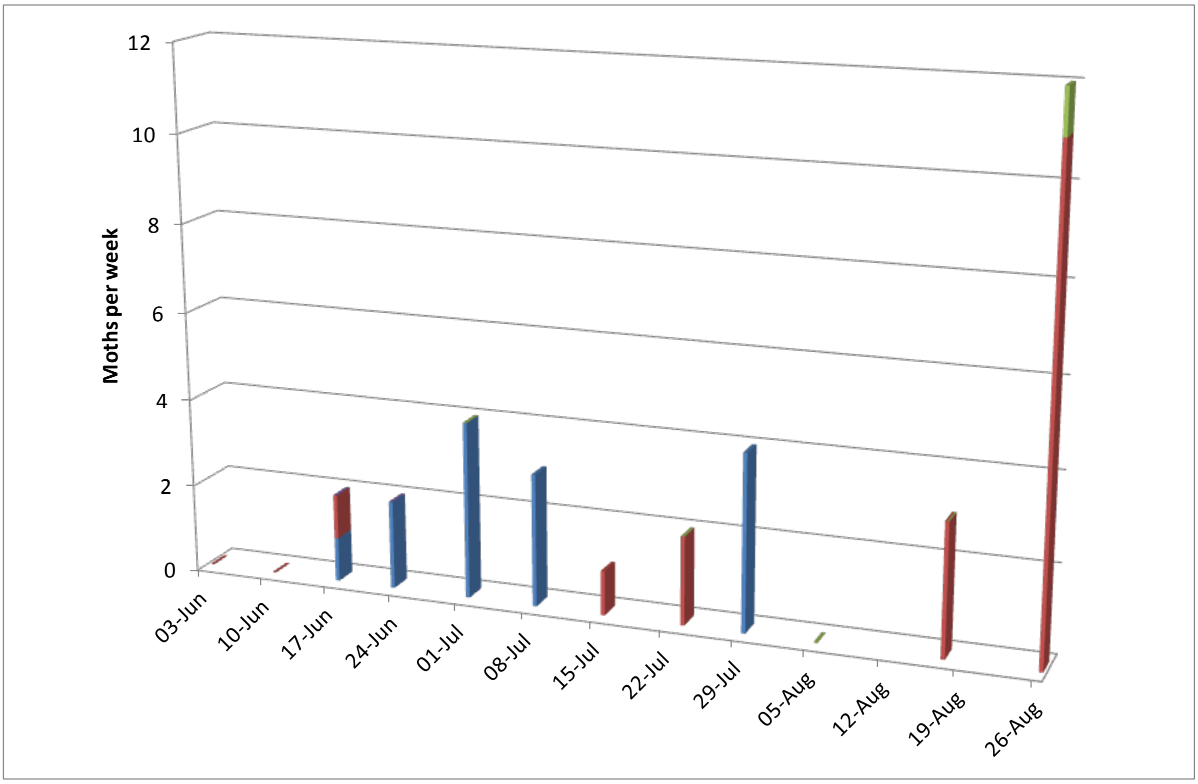


Figure 3.24. Captures of silver Y moths by Funnel traps in Scotland in 2015. Data provided by Kettle Produce.

Figure 3.25 compares captures by Funnel pheromone traps in 4 regions in 2015. Data have been summarised across all locations in each region (mean number of moths per trap per week) and are based on different numbers of traps at different times. Numbers captured vary depending on location, being particularly high in Lincolnshire but in all locations there are two main periods of activity between mid-June and mid-August and then from mid-September to mid-October.

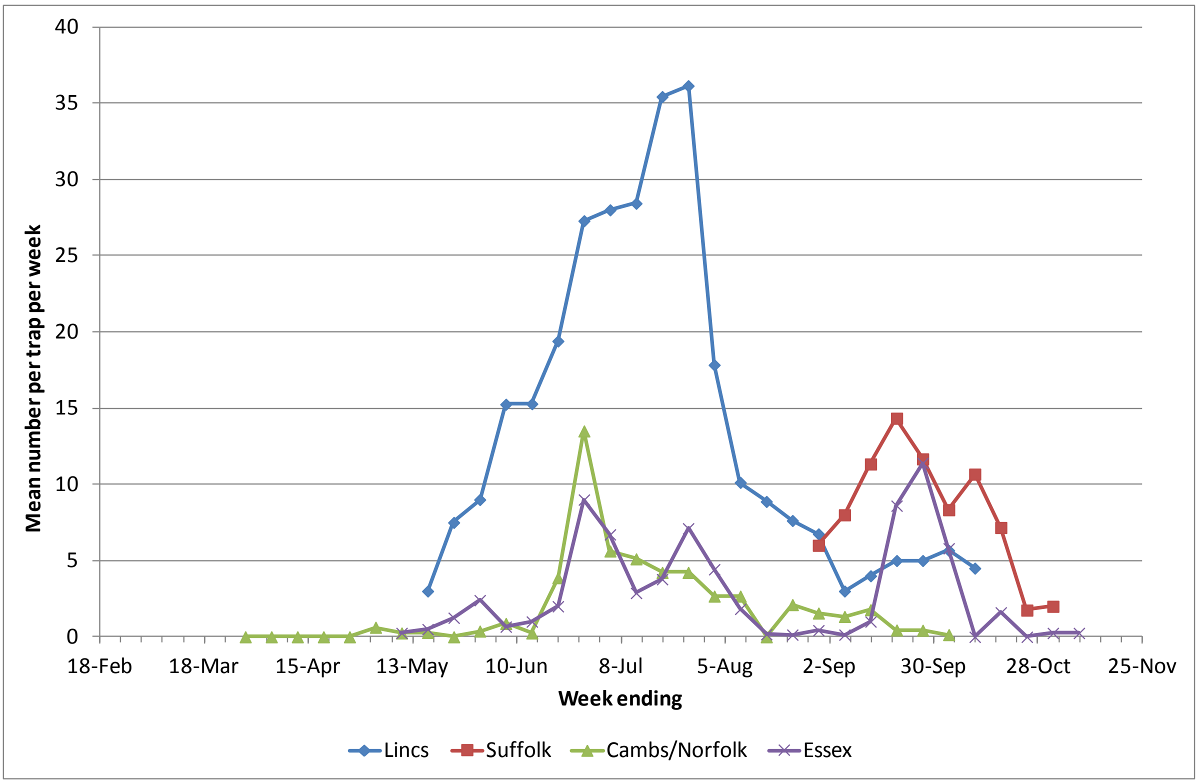


Figure 3.25. Captures by Funnel pheromone traps in 4 regions in 2015. Data have been summarised across all locations in each region (mean number of moths per trap per week) and are based on different numbers of traps at different times. Additional data provided by Ben Dodson and Andrew Poole.

Silver Y moth 2016

Captures by all of the Trapview traps in 2016 are summarised by county in Figure 3.26. Not all of the traps were fully operational in May but the figures show that moths were captured between May and September when trapping ceased. There is no evidence that moths were captured earlier at sites that were further south or further east, for example.

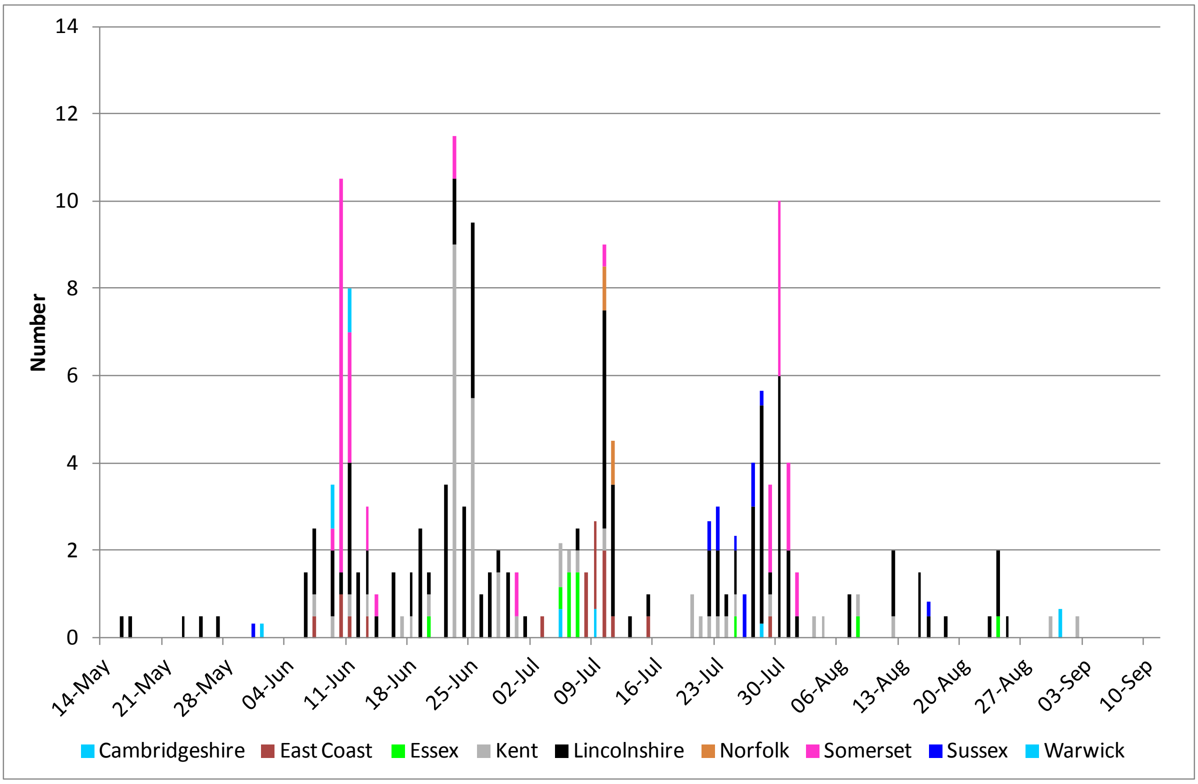


Figure 3.26. Captures of silver Y moths by Trapview traps in 2016 (moths per trap per day in each county).

A relatively large number of traps were again deployed in crops of lettuce grown by G's. This was to obtain more detailed information on silver Y moth activity both from using traps and by monitoring crops. Some of the data collected is summarised below.

Figure 3.27 shows the numbers of moths captured per trap per week in the 'ordinary' funnel pheromone traps in 13 locations at G's in 2016. The main period of activity was between mid-June and mid-August and a maximum of 81 moths per trap was captured in one week. There was considerable variation between locations in the pattern of moth activity as represented by trap captures.

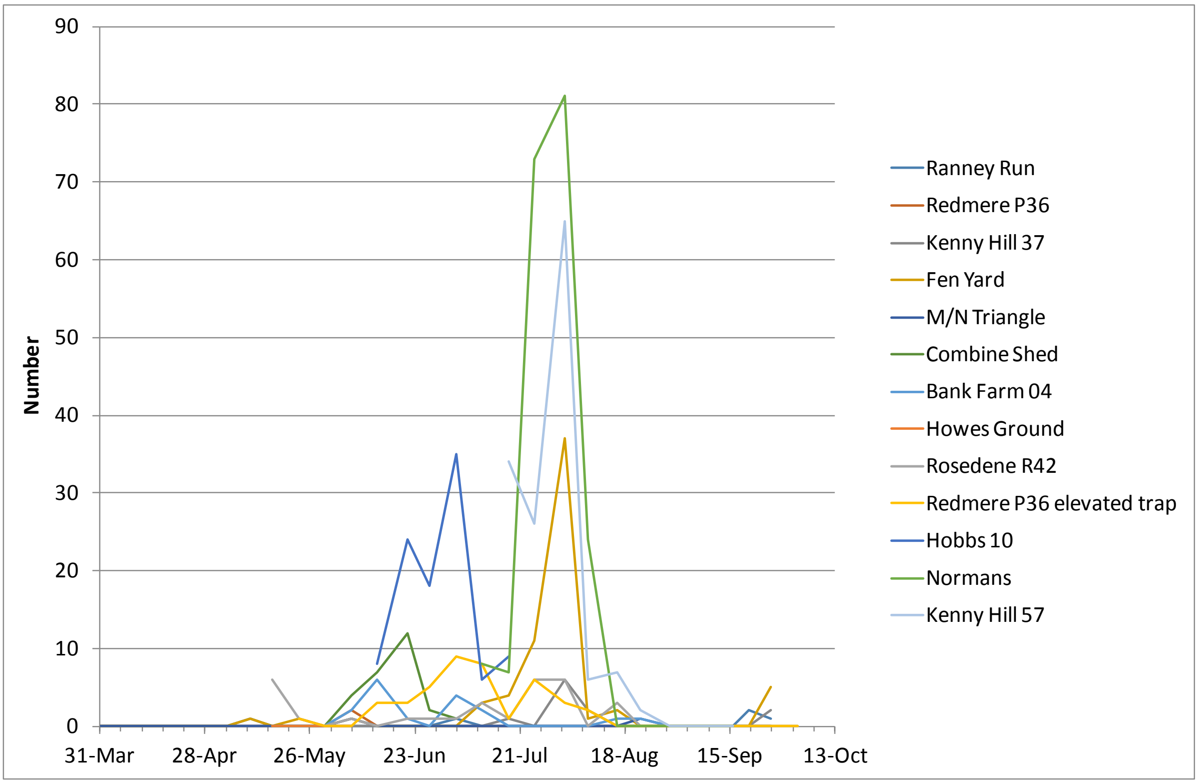


Figure 3.27. Captures of silver Y moths by 13 Funnel traps in G's crops in 2016.

Table 3.7 summarises captures at G's in 2016 in terms of the mean, maximum and minimum number of moths captured per week. As in 2014 and 2015, numbers varied considerably between locations.

Table 3.7. Captures of male silver Y moths at G’s in 2016 terms of the mean, maximum and minimum number of moths captured per week.

Week	Mean number of moths per trap per week	Number of traps running	Maximum number captured per trap	Minimum number captured per trap
29-Mar-16	0	5	0	0
4-Apr-16	0	5	0	0
12-Apr-16	0	5	0	0
19-Apr-16	0	5	0	0
26-Apr-16	0	5	0	0
4-May-16	0	5	0	0
10-May-16	0.40	5	1	0
16-May-16	0.67	9	6	0
23-May-16	0.30	10	1	0
30-May-16	0	10	0	0
6-Jun-16	1.10	10	4	0
13-Jun-16	2.40	10	8	0
21-Jun-16	4.10	10	24	0
27-Jun-16	2.60	10	18	0
4-Jul-16	5.10	10	35	0
11-Jul-16	3.00	10	8	0
18-Jul-16	5.18	11	34	0
25-Jul-16	12.20	10	73	0
2-Aug-16	19.80	10	81	0
8-Aug-16	3.50	10	24	0
16-Aug-16	1.30	10	7	0
22-Aug-16	0.40	10	2	0
30-Aug-16	0	10	0	0
8-Sep-16	0	9	0	0
16-Sep-16	0	9	0	0
20-Sep-16	0.29	7	2	0
26-Sep-16	1.14	7	5	0
3-Oct-16	0	2	0	0

Figures 3.28, 3.29 and 3.30 compare the captures of silver Y moths at G's by Trapview traps with captures by Funnel pheromone traps. The data are compared for the crops within a county/region – so either the traps in crops in Cambridgeshire or those in Norfolk or on the East Coast. Overall the patterns of activity were similar, but not identical. Again differences in the pattern of captures may be simply a reflection of background variation between traps or of the effect of local vegetation etc on the silver Y moth population.

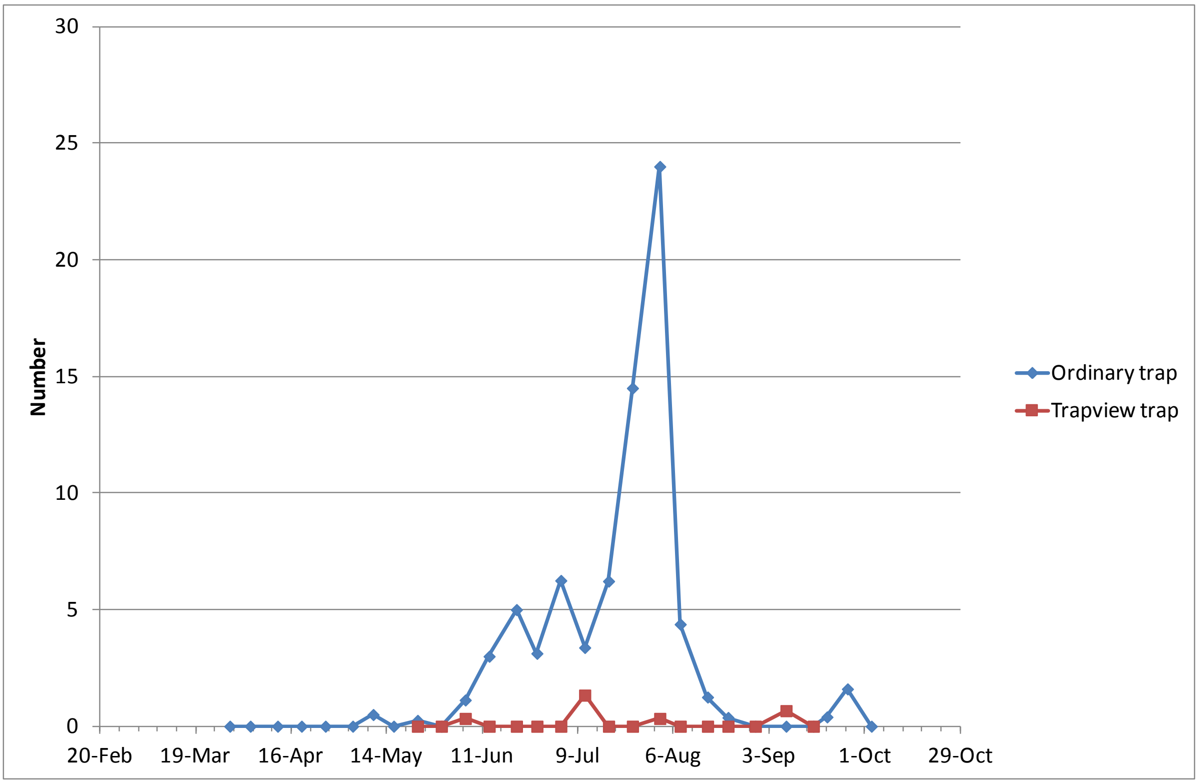


Figure 3.28. Captures of silver Y moths by Trapview traps and Funnel traps in G's crops in Cambridgeshire 2016.

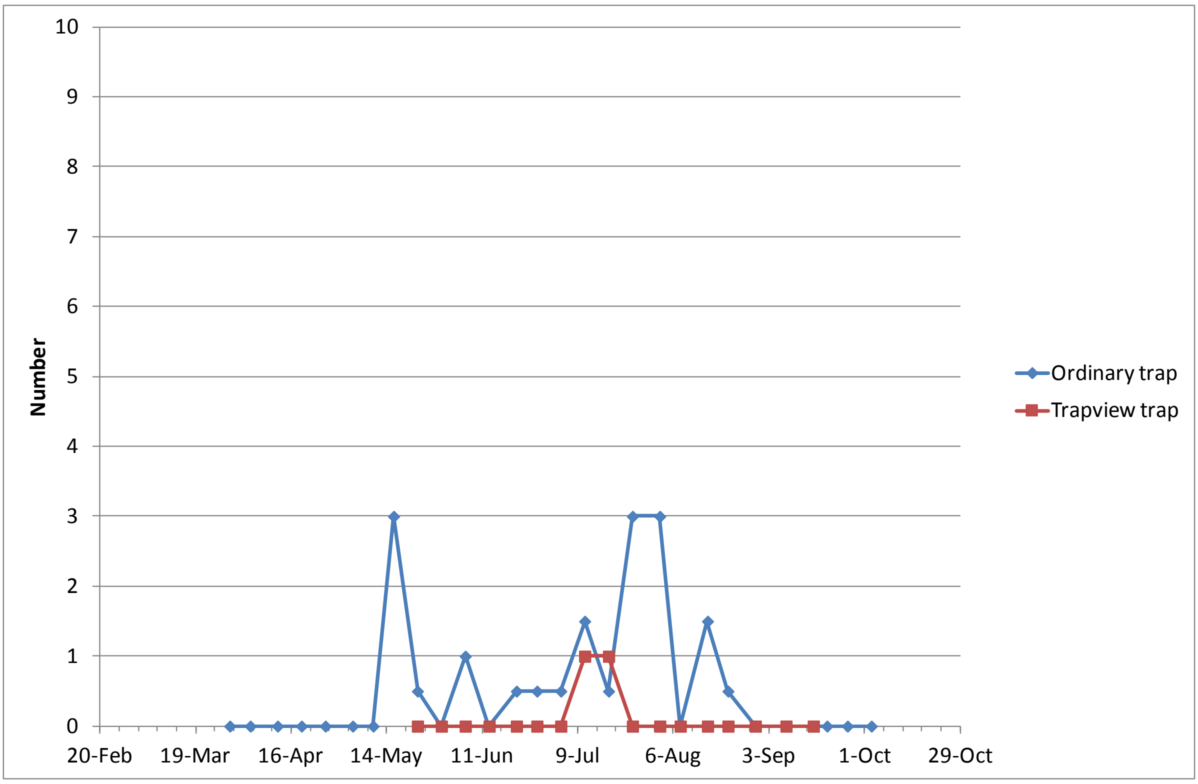


Figure 3.29. Captures of silver Y moths by Trapview traps and Funnel traps in G's crops in Norfolk 2016.

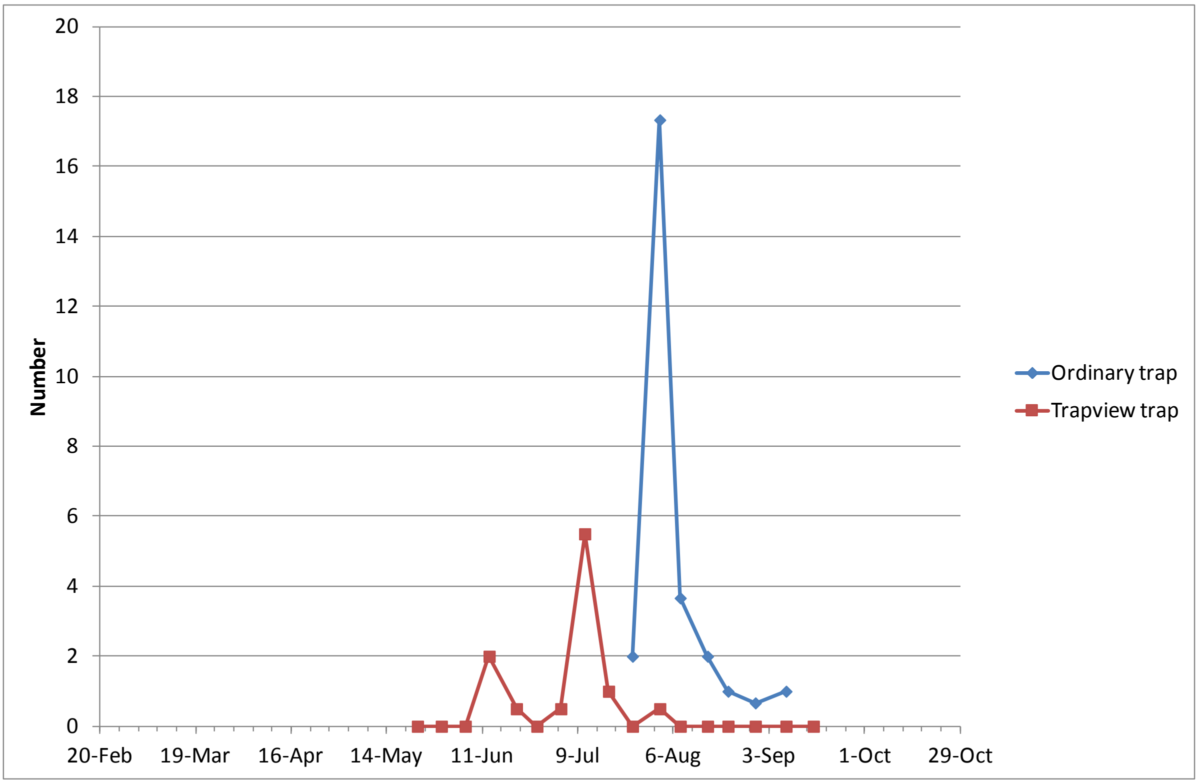


Figure 3.30. Captures of silver Y moths by Trapview traps and Funnel traps in G's crops in East Coast 2016.

Figure 3.31 shows the captures of silver Y moths by the Trapview and funnel traps in Essex. Very low numbers of moths were captured overall.

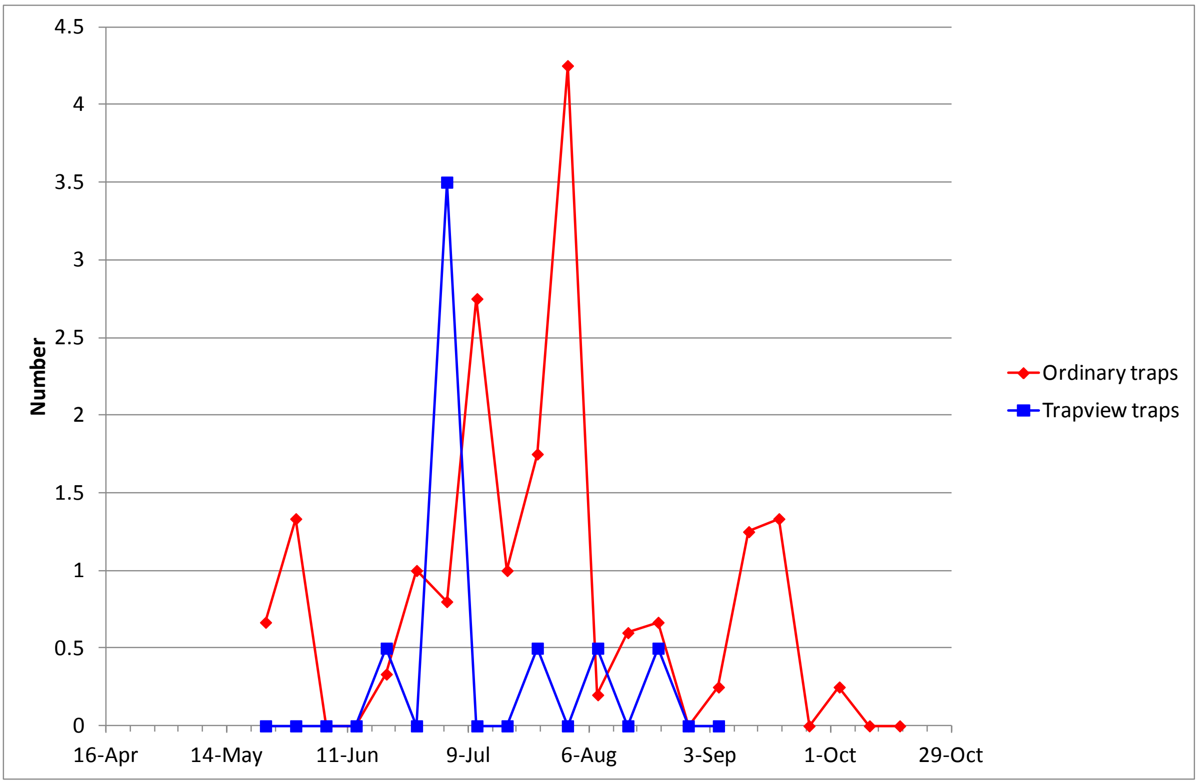


Figure 3.31. Captures of silver Y moths by Trapview traps and Funnel traps in Essex in 2016. Data provided by Andrew Poole.

Figure 3.32 shows the captures of silver Y moths by Trapview and funnel traps in Lincolnshire in 2016. Captures by a Trapview trap modified to incorporate a funnel trap (as in Figure 3.33) were comparable with the funnel traps. Another modified Trapview trap in Kent also appeared to capture higher numbers of moths (47 in the season compared with 6 moths captured a nearby unmodified Trapview trap) but there are no comparable data from an ordinary Funnel trap.

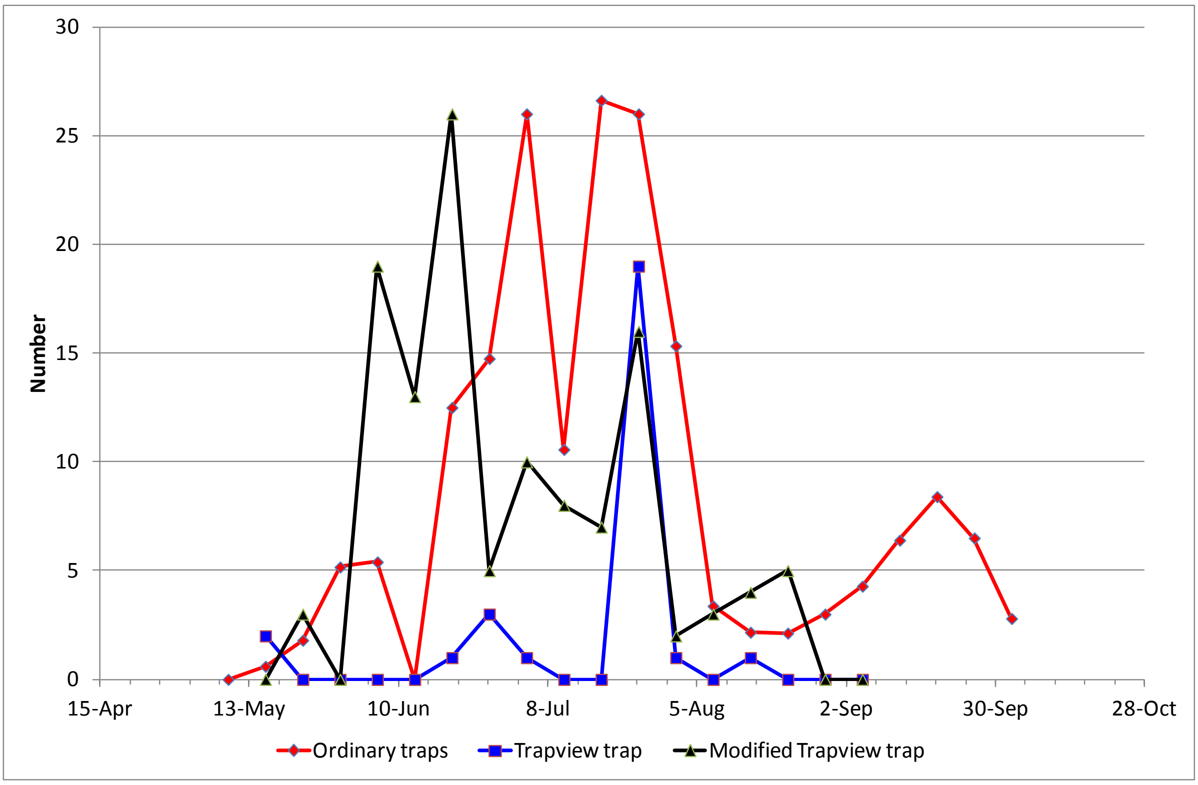


Figure 3.32. Captures of silver Y moths by Trapview traps and funnel traps in Lincolnshire in 2016. Data provided by Ben Dodson.

Figure 3.33. Modified Trapview trap.

Figure 3.34 shows the captures of silver Y moths by Trapview and funnel traps in Kent in 2016. Captures by the Trapview traps were again considerably lower than by the funnel traps.

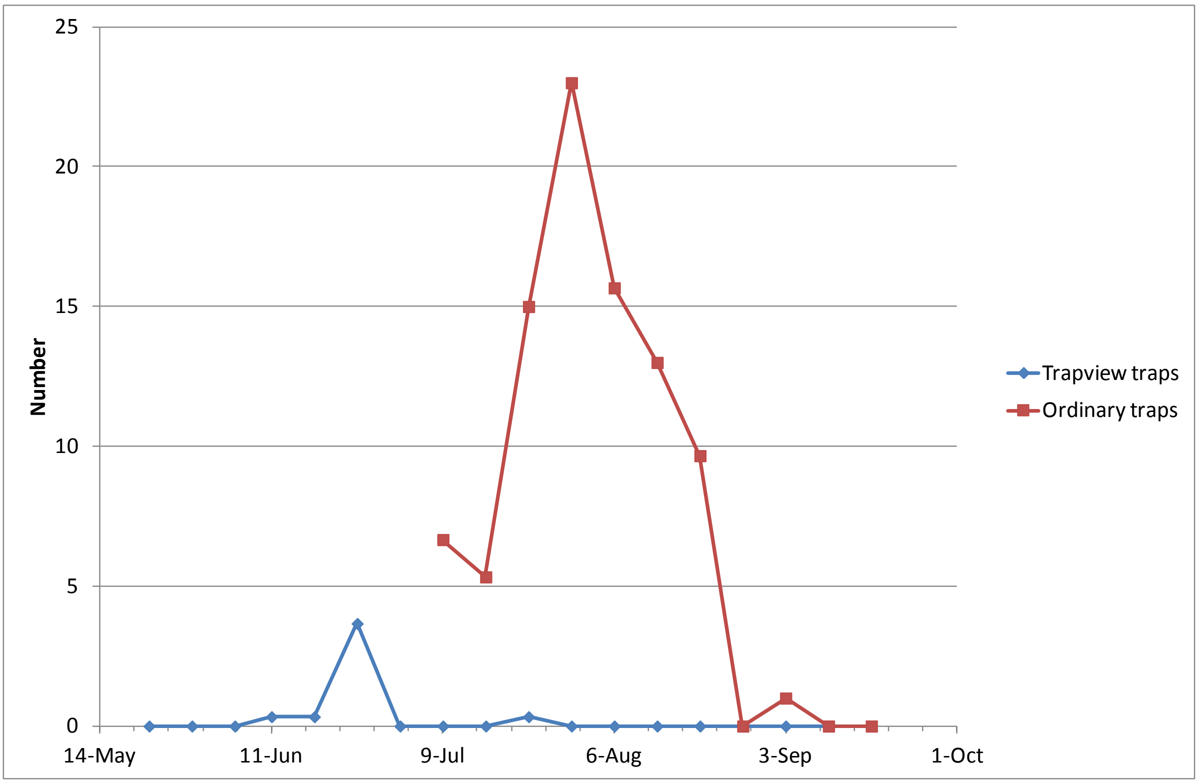


Figure 3.34. Captures of silver Y moths by Trapview traps and funnel traps in Kent in 2016. Data provided by Intercrop.

Finally, Table 3.8 compares the numbers of silver Y moths captured by Trapview traps and nearby Funnel traps in different locations (crops of pea) in Somerset. The two types of trap captured similar numbers of moths overall but there was considerable variation in the pattern of captures.

Table 3.8. The numbers of silver Y moths captured by Trapview traps and nearby Funnel traps in different locations (crops of pea) in Somerset 2016. Data provided by Andrew Rutherford,

Date	Funnel Trap	Trapview	Location	Date	Funnel Trap	Trapview	Location
09-Jun	set		1	08-Jun	set		3
17-Jun	2	14	1	14-Jun	1	14	3
24-Jun	2	0	1	21-Jun	3	0	3
01-Jul	5	0	1	27-Jun	2	2	3
07-Jul	set		2	27-Jun	set		4
14-Jul	2	1	2	05-Jul	0	2	4
20-Jul	3	0	2	14-Jul	1	0	4
27-Jul	3	0	2	20-Jul	4	0	4
05-Aug	1	1	2	26-Jul	3	0	4
16-Aug	4	0	2	28-Jul	set		5
				04-Aug	4	17	5
				12-Aug	6	0	5
Total	22	16			24	35	

Data from Funnel pheromone traps in 2016

Figure 3.35 compares captures by Funnel pheromone traps in 4 regions in 2016. Data have been summarised across all locations in each region (mean number of moths per trap per week) and are based on different numbers of traps at different times. Numbers captured vary depending on location, but in all locations there was one main period of activity between mid-July and mid-August and some further activity around mid-September.

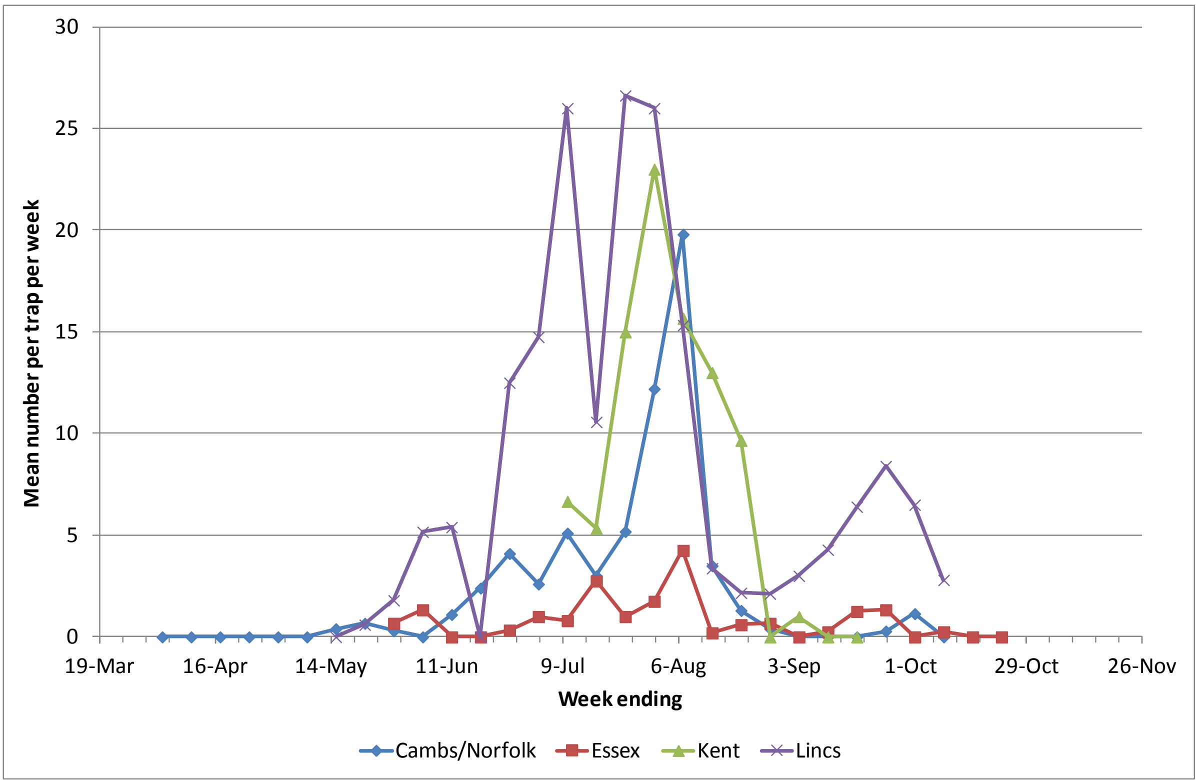


Figure 3.35. Captures by Funnel pheromone traps in 4 regions in 2016. Data have been summarised across all locations in each region (mean number of moths per trap per week) and are based on different numbers of traps at different times. Additional data provided by Andrew Poole, Intercrop and Ben Dodson.

Performance of the Trapview traps used to capture silver Y moth

Colin Carter helped the trap hosts to set up their traps and provided ongoing support for the trap network. He monitored the traps using the Trapview website and contacted the hosts when there were problems. He also recorded lure changes.

The traps are still in the development phase and there were a few problems with them which the company hopes to improve on. In 2015 the surface of the sticky inserts was not sufficiently sticky to hold some of the silver Y moths firmly and there was evidence that they had moved around and sometimes escaped from the trap. It seemed that once a few moths had been captured then the performance of the traps declined – possibly because the available area for capturing moths had decreased. The camera is relatively heavy and in some cases the trap became distorted, which affected the view of the sticky surface. On some days the signal was insufficient for the image to be sent to the Trapview web site.

Overall the Trapview traps captured lower numbers of moths in 2015 and this led Colin Carter to modify two of the traps to see if captures could be increased (Figure 3.33). One of these was run at JEPCO (see Figure 3.32 above) and the other at Warwick Crop Centre. The trap at JEPCO did capture more moths than the non-modified trap. Captures at Warwick Crop Centre were too low overall to determine if there was a positive effect.

Relationship between captures by pheromone traps and infestation of crops by larvae

2015

Attempts were made to relate infestations in crops to the numbers of moths captured in pheromone traps – in terms of timing and abundance. It is worth emphasising that as these were commercial crops they were subject to spray programmes which may have had an impact on infestations. Captures of silver Y moths in 2015 were relatively low and so infestations in lettuce crops were not severe. However, where available, crop walking data were compared with trap captures to determine how much ‘warning’ they might provide and whether there were indications that a threshold might be developed. In Lincolnshire, larvae and damage were observed in July, with the first larva seen in week 27 (first week of July) which coincided with the period of greatest moth activity (Figures 3.18 and 3.19).

Crop walking data collected at G’s are summarised and compared with trap captures by Funnel pheromone traps in Figures 3.36 and 3.37 for the crops in Cambridgeshire and Norfolk respectively. Infestations were scored: 0= none seen; 1= >1 larva/100plants; 2= 1/50 plants; 3=1/25plants; 4=1/10plants; 5= <1/1+ and are expressed on the graphs as number of plants infested out of 100. Peak numbers of larvae were observed in mid-July which seemed to tie in most closely with the influx of moths around 23 June.

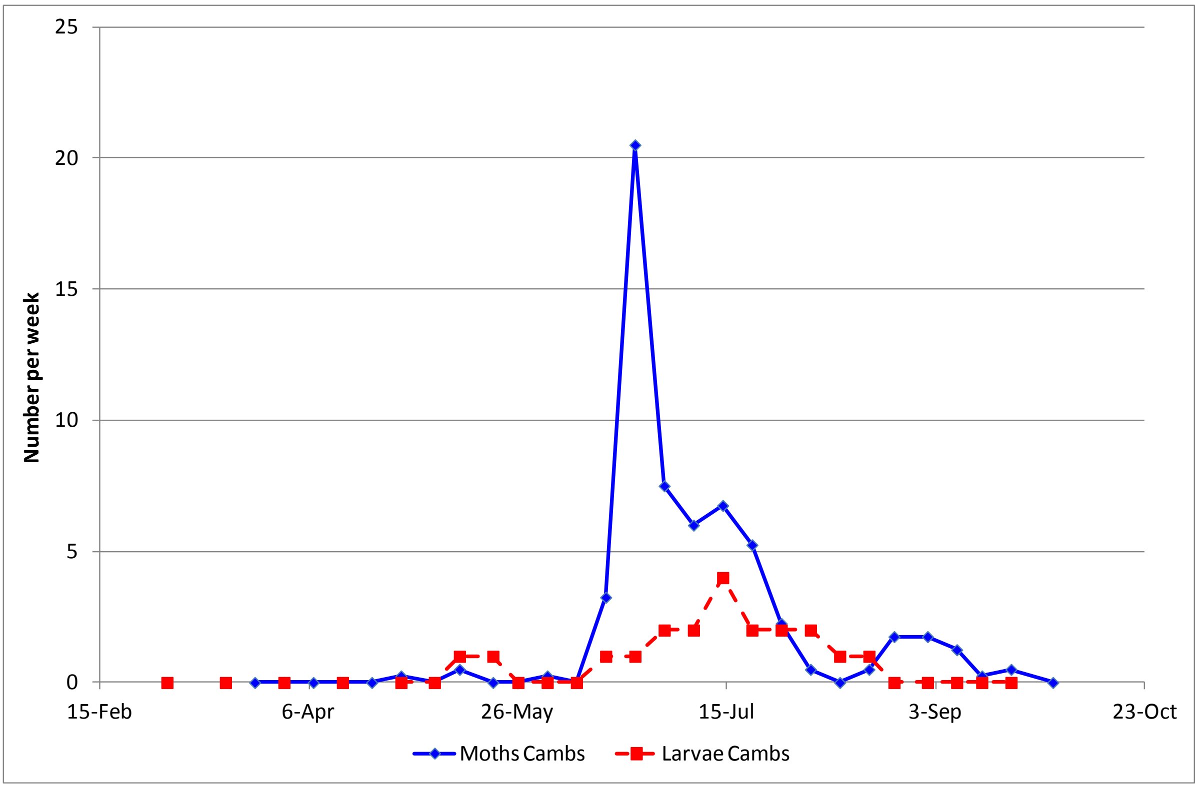


Figure 3.36. Captures of silver Y moths compared with crop walking records on the presence of larvae in G's crops in Cambridgeshire in 2015. In the original data sets, larval infestations were scored: 0= none seen; 1= >1/100plants; 2= 1/50 plants; 3=1/25plants; 4=1/10plants; 5= <1/1+. In order to plot them on the graph the scores are expressed as the number of plants infested out of 100.

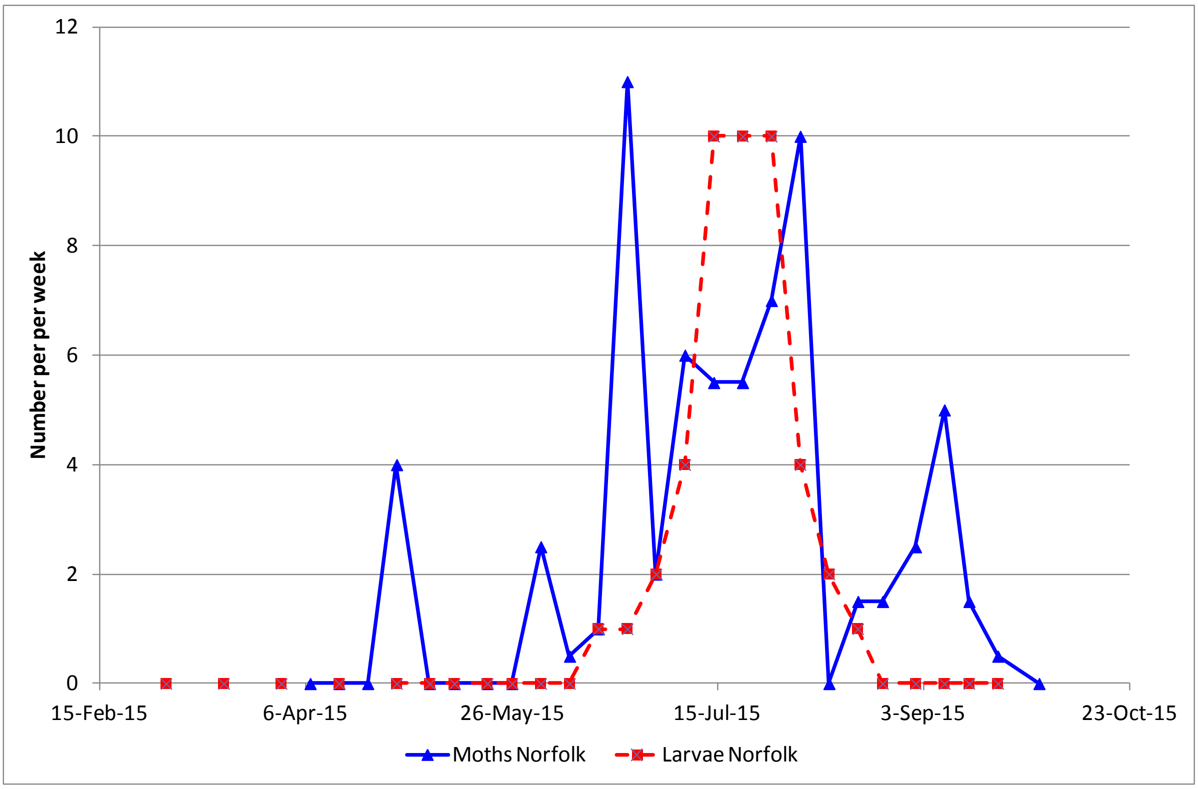


Figure 3.37. Captures of silver Y moths compared with crop walking records on the presence of larvae in G's crops in Norfolk in 2015. In the original data sets, larval infestations were scored: 0= none seen; 1= >1/100plants; 2= 1/50 plants; 3=1/25plants; 4=1/10plants; 5= <1/1+. In order to plot them on the graph the scores are expressed as the number of plants infested out of 100.

2016

Crop walking data collected at G's are summarised and compared with trap captures by Funnel pheromone traps in Figures 3.38, 3.39 and 3.40 for the crops in Cambridgeshire, Norfolk and on the East Coast respectively. Infestation levels were low, as were the numbers of moths captured at the Norfolk sites. As far as could be ascertained, the low levels of infestation with larvae reflected moth activity.

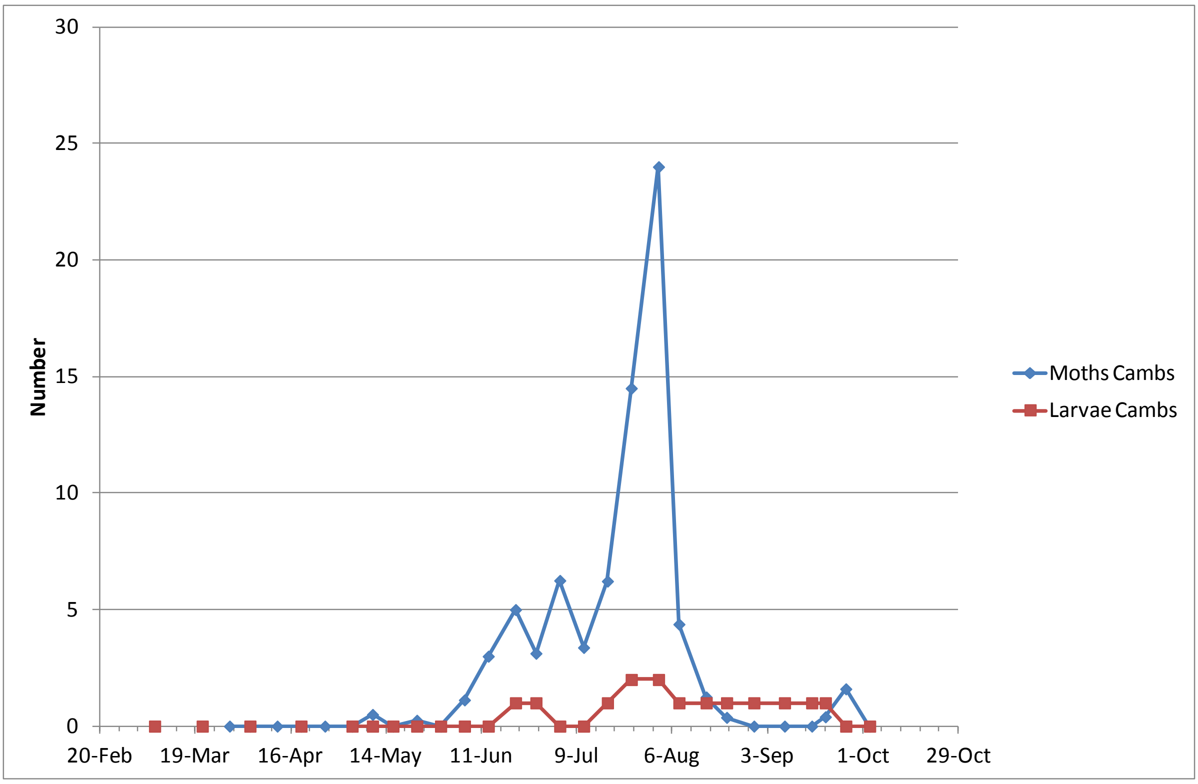


Figure 3.38. Captures of silver Y moths (mean numbers captured in Funnel pheromone traps) compared with crop walking records on the presence of larvae in G's crops in Cambridgeshire in 2016. In the original data sets, larval infestations were scored: 0= none seen; 1= >1/100plants; 2= 1/50 plants; 3=1/25plants; 4=1/10plants; 5= <1/1+. In order to plot them on the graph the scores are expressed as the number of plants infested out of 100.

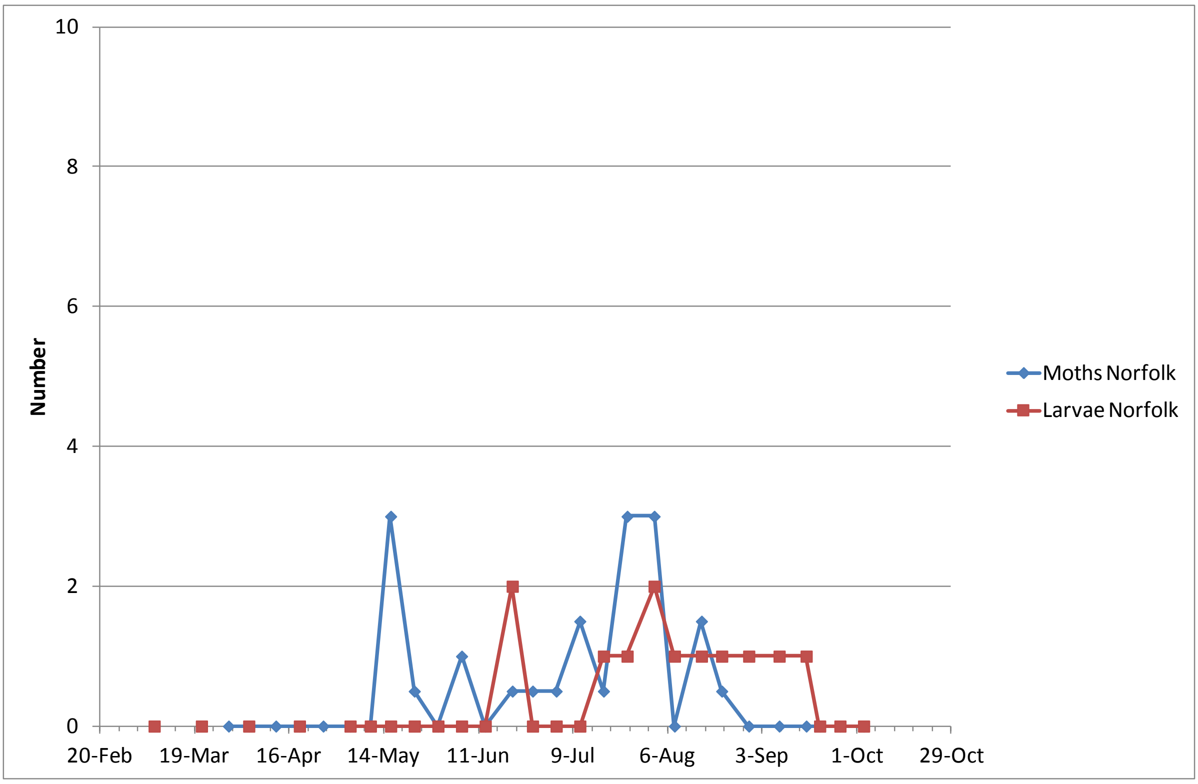


Figure 3.39. Captures of silver Y moths (mean numbers captured in Funnel pheromone traps) compared with crop walking records on the presence of larvae in G's crops in Norfolk in 2016. In the original data sets, larval infestations were scored: 0= none seen; 1= >1/100plants; 2= 1/50 plants; 3=1/25plants; 4=1/10plants; 5= <1/1+. In order to plot them on the graph the scores are expressed as the number of plants infested out of 100.

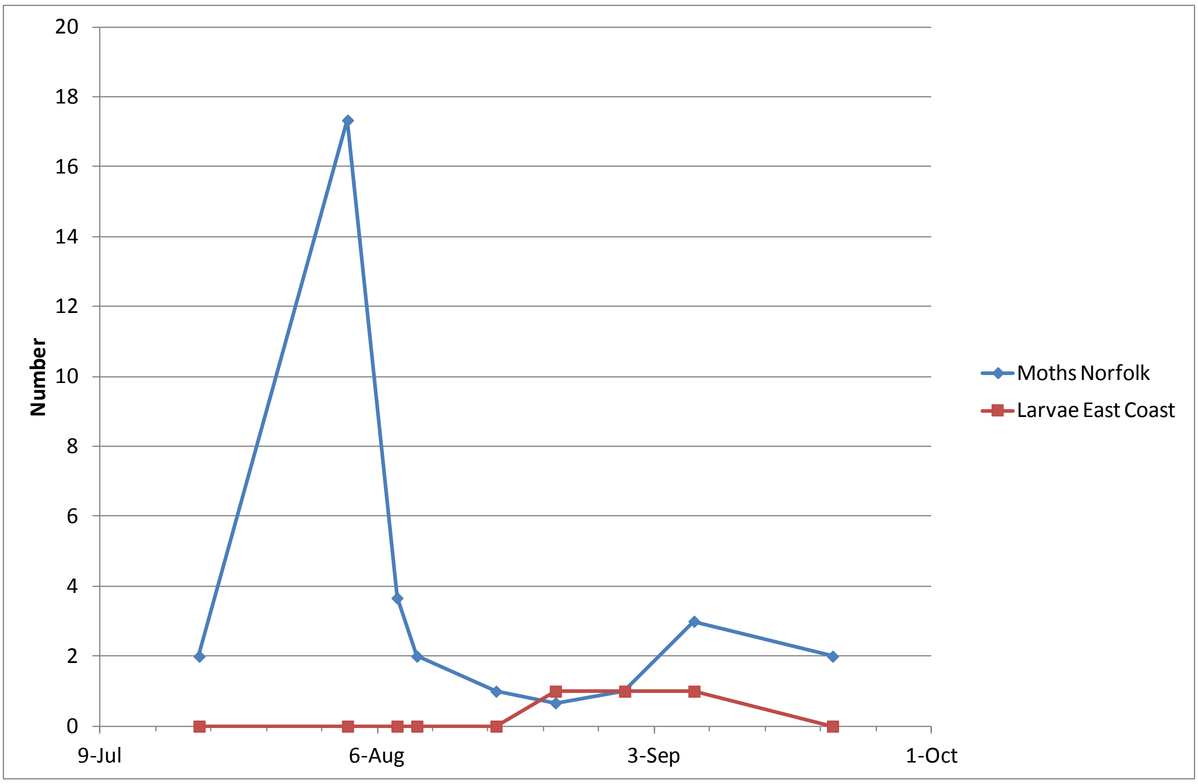


Figure 3.40. Captures of silver Y moths (mean numbers captured in Funnel pheromone traps) compared with crop walking records on the presence of larvae in G's crops on the East Coast in 2016. In the original data sets, larval infestations were scored: 0= none seen; 1= >1/100plants; 2= 1/50 plants; 3=1/25plants; 4=1/10plants; 5= <1/1+. In order to plot them on the graph the scores are expressed as the number of plants infested out of 100.

Figure 3.41 shows the relationship between the mean numbers of moths captured per week and incidences of infestation by larvae in Lincolnshire. There is good agreement in the relative timing of peaks of moth activity and occurrence of larvae in crops but the scale of the relationship between larval incidence and moth numbers differs across the season.

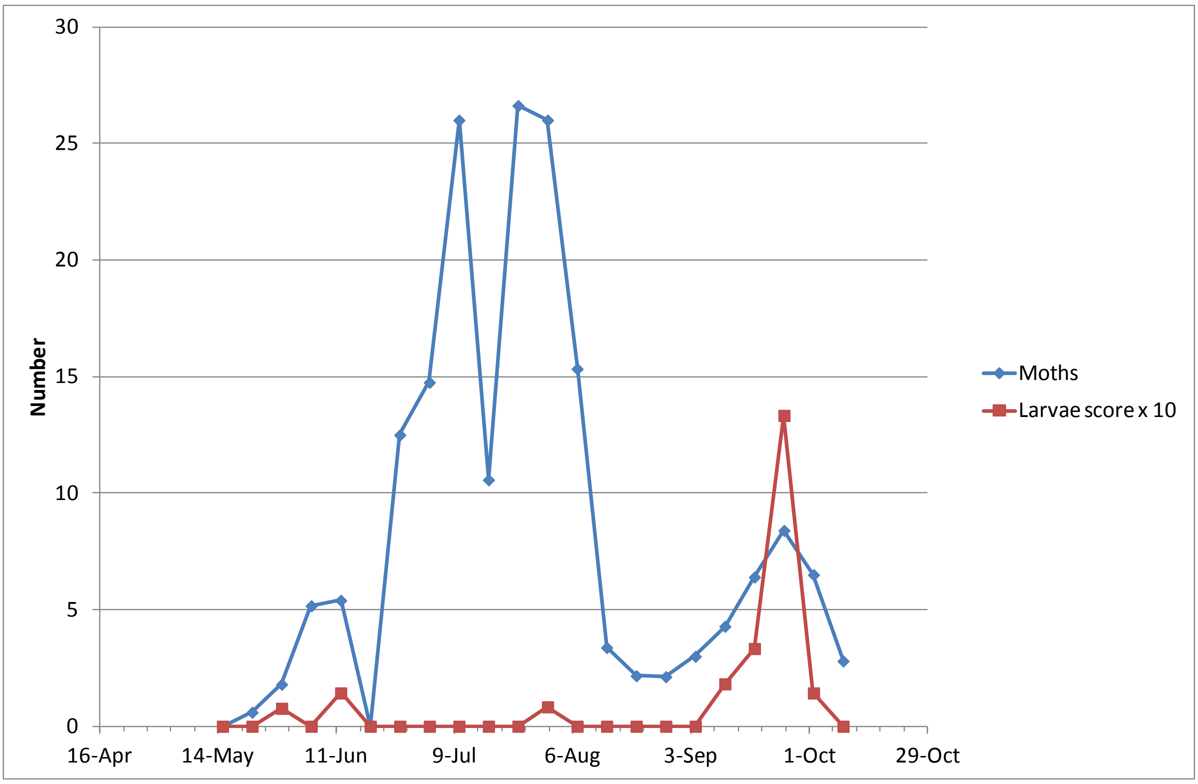


Figure 3.41. Captures of silver Y moths (mean numbers captured in Funnel pheromone traps) compared with crop walking records on the presence of larvae in JEPCO crops in 2016. Larval infestations were scored and are multiplied by 10 to show them more clearly on the same y axis. Data provided by Ben Dodson.

Relationship between the timing of moth captures and the detection of larvae in crops

In order to try and understand the relationship between the timing of moth captures and the detection of larvae in crops, data on development of the different stages of silver Y moth at different temperatures (Hill and Gatehouse, 1992; Saito, 2007) were summarised. Table 3.9 shows the durations of the different stages at a range of temperatures.

Table 3.9. Durations of the egg, larval and pupal stages of development of the silver Y moth at a range of temperatures. Data from Saito (2007)[1] and Hill & Gatehouse (1992)[2].

	Development time in days		
Temperature °C	**Egg[1]**	**Larva[2]**	**Pupa[2]**
13	11	51	31
16		34	19
18	6		
19		23	13
22		21	10
23	4		
25		16	8
28	3		

Figure 3.42 shows the relationship between the rate of development (100/time) and temperature for each stage. From the lines fitted in Figure 3.42 it is possible to estimate the low temperature threshold for each stage and from this to estimate the day-degree requirement for each stage. The estimated threshold temperatures for the egg, larval and pupal stages are 7.6, 9.2 and 7.7°C respectively. Using the estimates of development time at 13 and 18°C, egg development required approximately 60 day-degrees above 7.7°C.

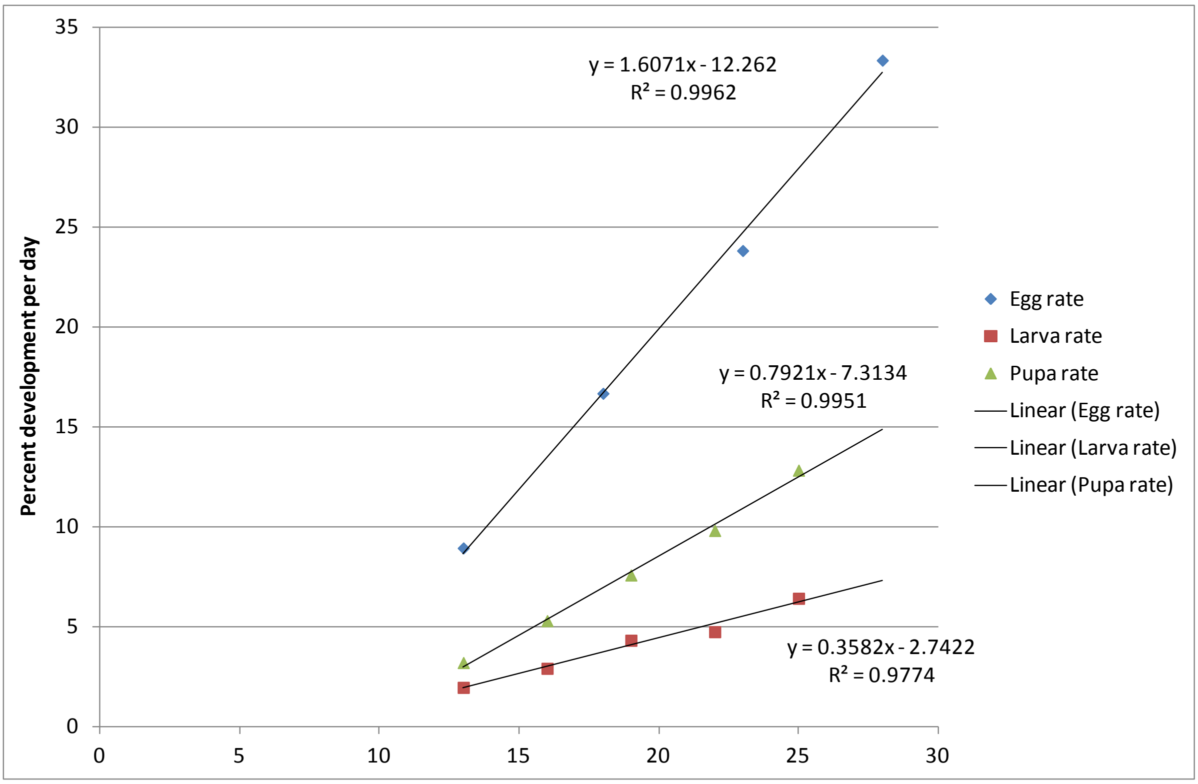


Figure 3.42. Relationship between the rate of development (100/time) and temperature for each stage of development of the silver Y moth. Data from Hill & Gatehouse (1992) with the exception of the egg stage which is from Saito (2007).

As an example, four sets of weather data collected for the AHDB Pest Bulletin in 2015 were used to estimate the daily day-degrees above 7.7ºC between mid-June and mid-August (Table 3.10). Overall, trap catch data showed that the largest numbers of moths were captured from 13 June until towards the end of July. Using the day-degree sum for egg hatch of approximately 60 day-degrees above 7.7°C indicated that, for example, eggs laid on 14 June in Kent would hatch approximately 9 days later. Using another example, when the weather was warmer, eggs laid on 25 June in south Lincolnshire would hatch approximately 6 days later.

Table 3.10. Daily day-degrees between 13 June and 12 July 2015 in 4 locations. Weather data from AHDB Pest Bulletin project. The day-degree sum for silver Y moth eggs to hatch is approximately 60 day-degrees above 7.7°C. So, for example, eggs laid on 14 June would hatch approximately 9 days later in Kent (6 + 5 + 5 + 10 + 9 + 7 + 8 + 8 + 6) = 60 day-degrees.

	Kent	Suffolk	Norfolk	South Lincolnshire
13/06/2015	8	7	5	4
14/06/2015	6	6	4	4
15/06/2015	5	4	3	4
16/06/2015	5	5	6	8
17/06/2015	10	10	8	9
18/06/2015	9	7	5	6
19/06/2015	7	6	5	5
20/06/2015	8	7	6	7
21/06/2015	8	9	7	7
22/06/2015	6	6	3	4
23/06/2015	6	5	3	4
24/06/2015	8	8	7	8
25/06/2015	9	9	9	10
26/06/2015	10	10	9	10
27/06/2015	10	11	9	10
28/06/2015	9	9	8	9
29/06/2015	10	9	10	10
30/06/2015	10	10	11	13
01/07/2015	15	15	15	16
02/07/2015	12	14	14	13
03/07/2015	10	10	8	9
04/07/2015	14	15	14	12
05/07/2015	8	9	9	9
06/07/2015	9	9	9	8
07/07/2015	9	11	9	9
08/07/2015	8	8	5	7
09/07/2015	7	6	5	7
10/07/2015	8	10	9	10
11/07/2015	12	13	11	11
12/07/2015	9	10	9	10

Diamond-back moth

Very low numbers of diamond-back moths were captured in the Trapview traps in 2015 (Figure 3.43). Data from ordinary (Delta) pheromone traps is available from the sites at Warwick and in Fife. Captures were very low in both locations and too low to undertake any meaningful analysis of the data.

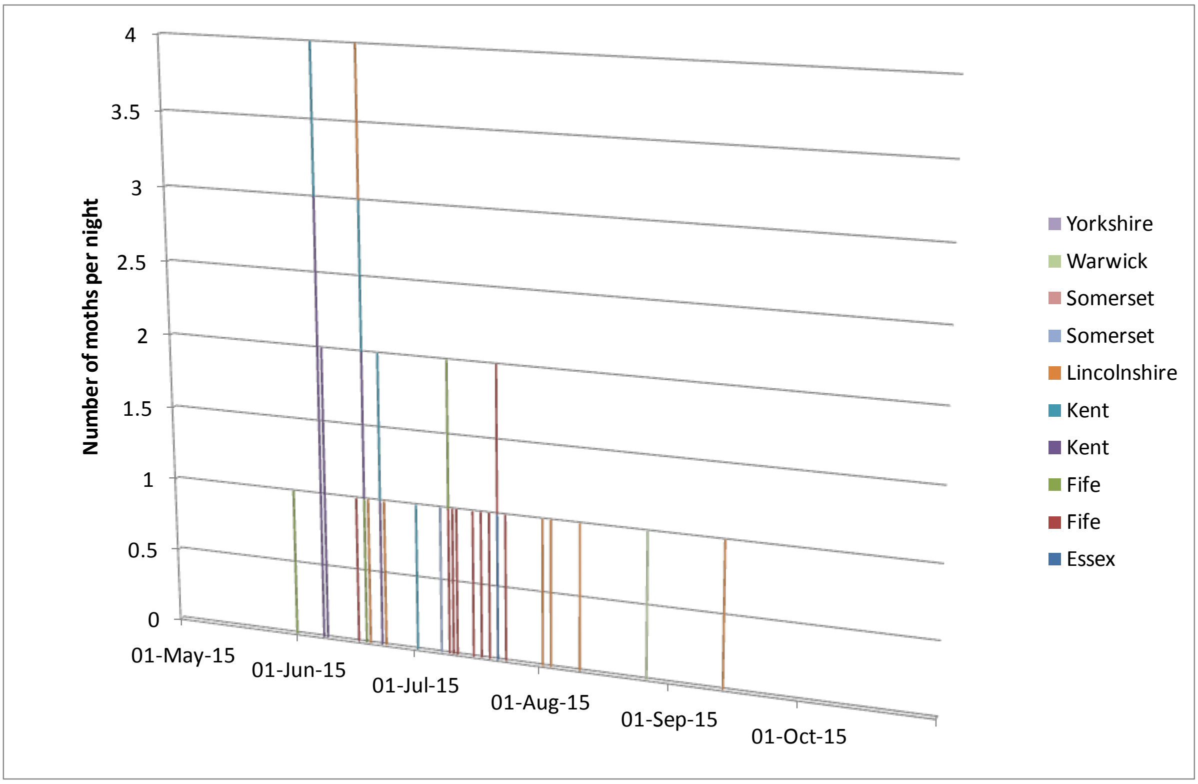


Figure 3.43. The numbers of diamond-back moths captured in 10 Trapview traps in 2015.

In 2016, larger numbers of diamond-back moths were captured overall by the Trapview traps (Figure 3.44). The single trap in Lincolnshire and one of the two traps in Kent caught the largest numbers during the period of high immigration and the first moths were captured between 3 and 4 June. There was good evidence of a subsequent generation in Lincolnshire (first moth captured on 17 July) and in the south-west (first moth captured on 10 July).

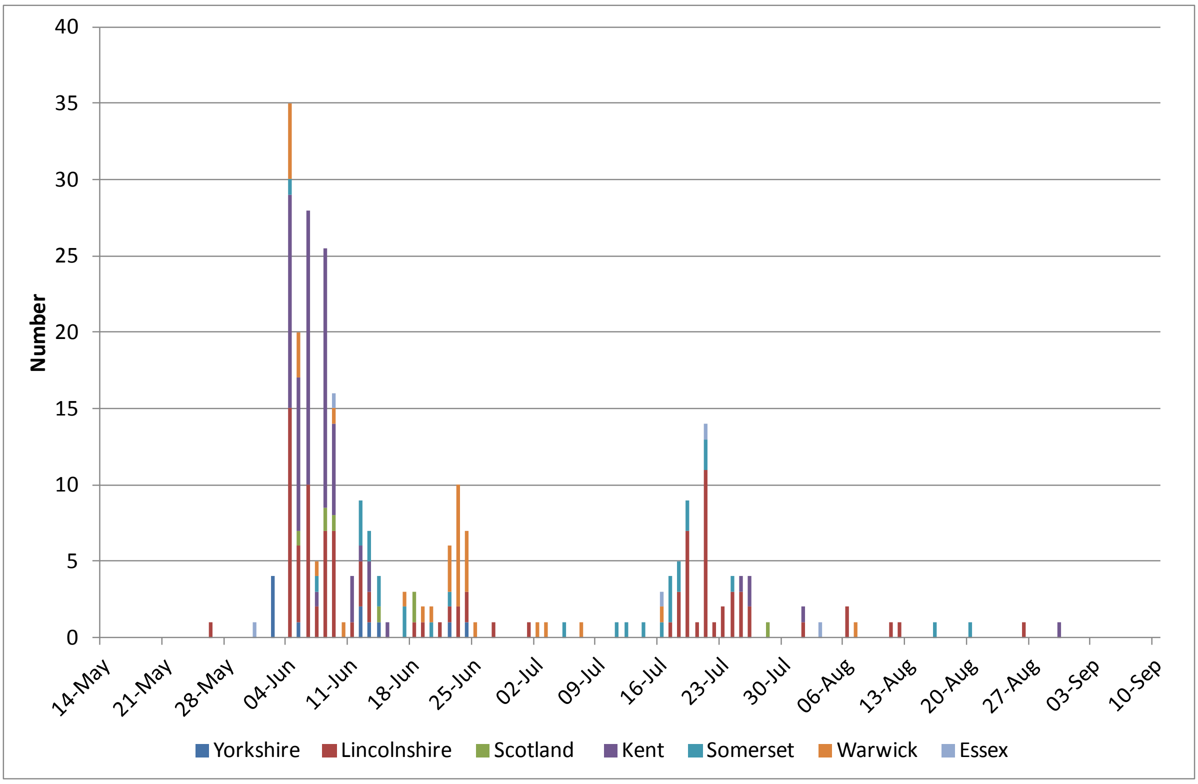


Figure 3.44. The numbers of diamond-back moths captured in 10 Trapview traps in 2016 and summarised by region (mean numbers per trap per day). There were 2 traps per region in Scotland, Kent and Somerset.

Figure 3.45 compares captures by the Trapview trap at Wellesbourne with captures by two ordinary Delta traps. The Trapview trap captured relatively few moths. At Wellesbourne there was evidence of a second generation which began on about 8 July.

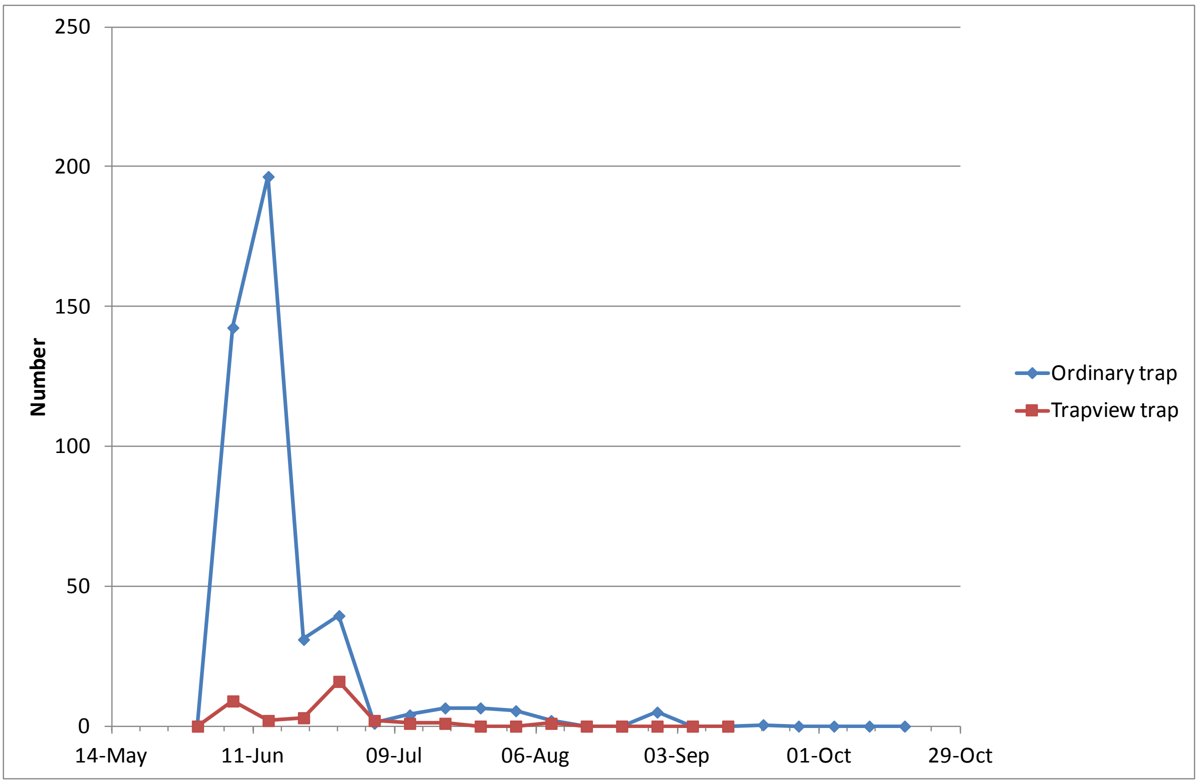


Figure 3.45. The numbers of diamond-back moths captured in at Wellesbourne in 2016 by the Trapview trap and two Delta traps (moths per trap per week).

Figures 3.46 and 3.47 compare captures of diamond-back moths by Trapview traps in Devon and Somerset with captures by Delta traps at the same locations. The Trapview traps again captured relatively few moths.

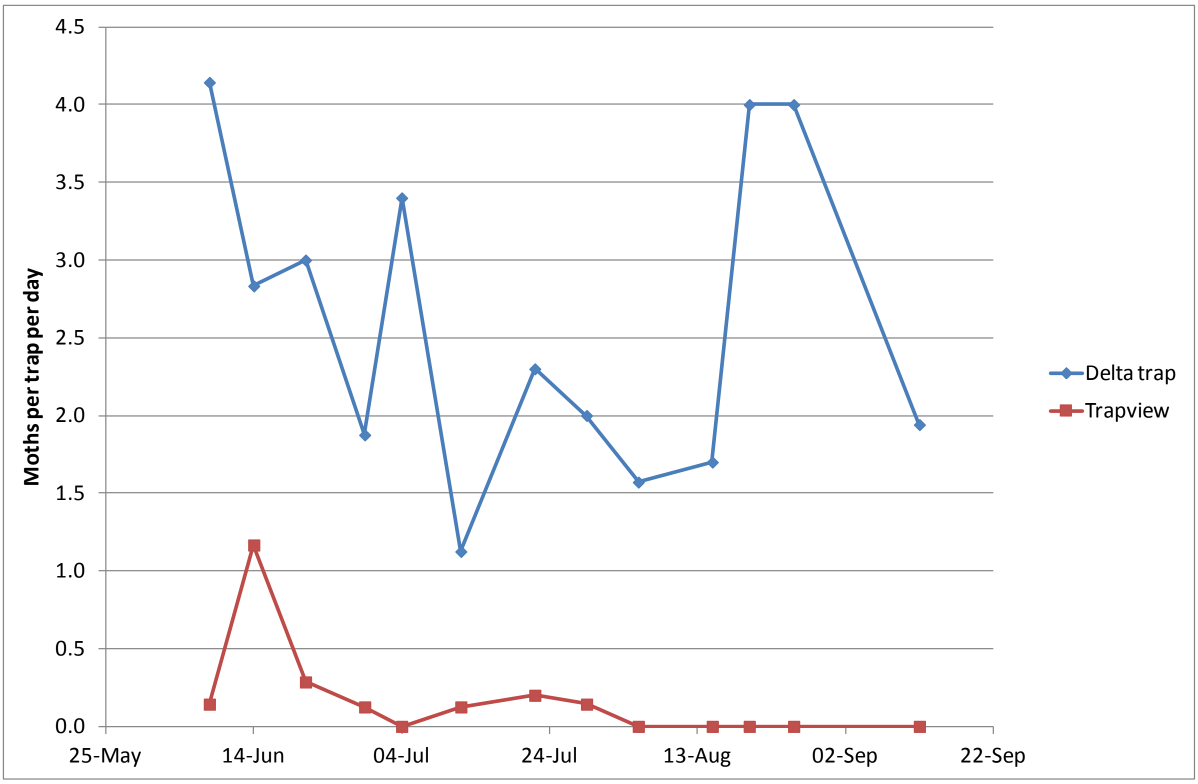


Figure 3.46. The numbers of diamond-back moths captured in Devon in 2016 by a Trapview trap and a nearby Delta trap (moths per trap per day). Data provided by Andrew Rutherford.

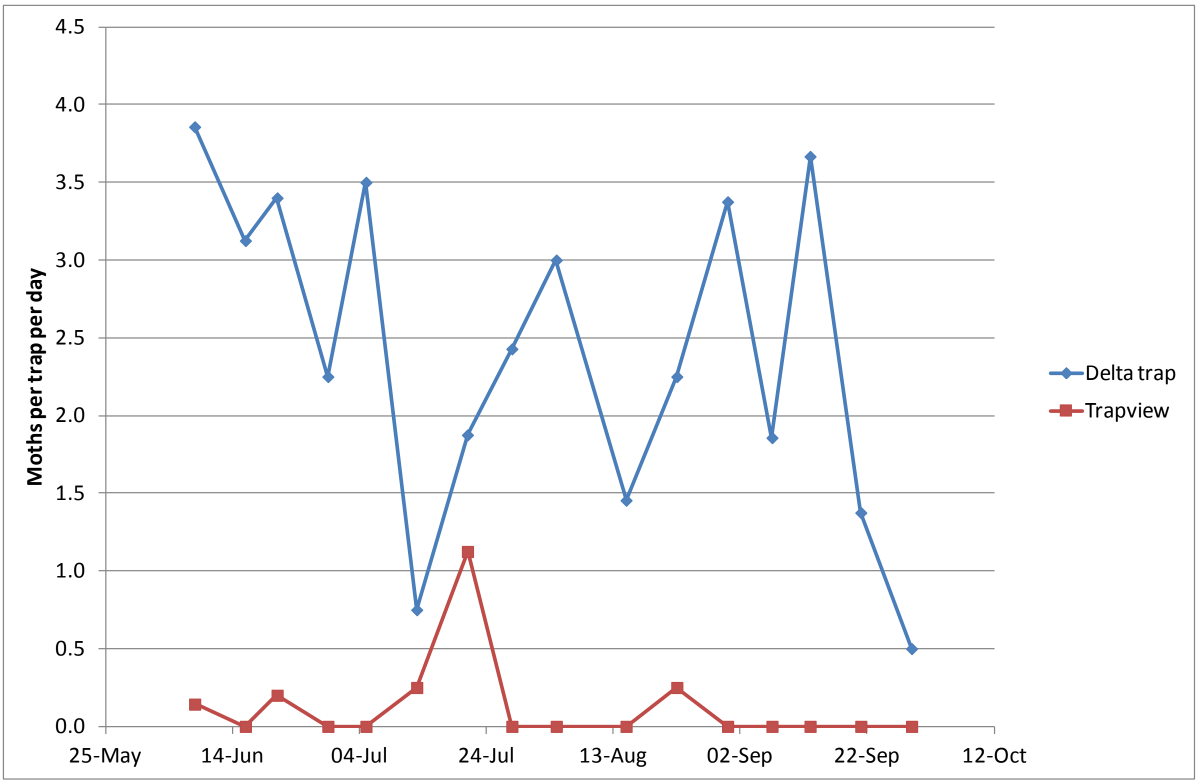


Figure 3.47. The numbers of diamond-back moths captured in Somerset in 2016 by a Trapview trap and a nearby Delta trap (moths per trap per day). Data provided by Andrew Rutherford.

Day-degrees between generations

As for the silver Y moth, data on development times of diamond-back moth (Liu et al., 2001) were plotted and are shown in Figure 3.48. At a temperature of 16°C, egg development took 6.4 days and a complete generation took approximately 33 days.

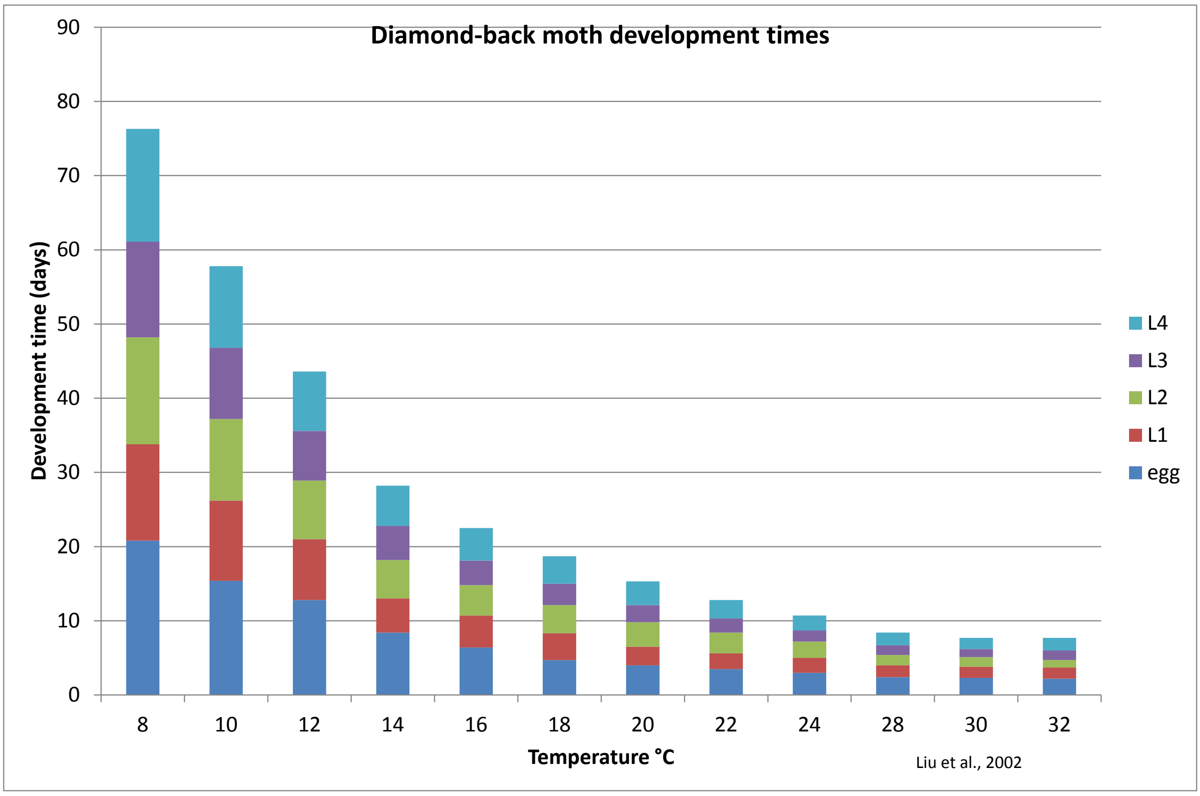


Figure 3.48. Development times for diamond-back moth eggs and larvae (Liu et al., 2001).

Using the data from Liu et al., the low temperature threshold for development (all stages) was estimated as 7.5°C (Figure 3.49).

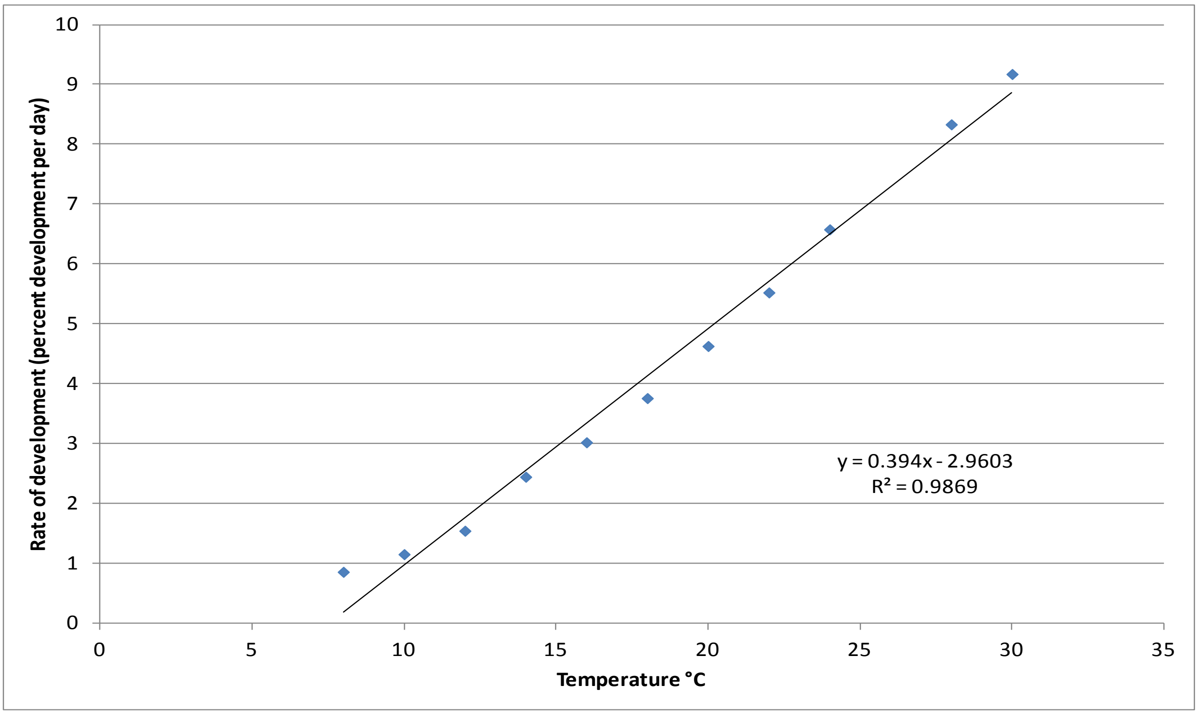


Figure 3.49. Relationship between rate of development and temperature for diamond-back moth (all stages) (data from Liu et al., 2001).

From the constant temperature data between 12 and 22°C (the range of temperatures that the diamond-back moth might be expected to experience in mid-summer in the UK), the total day-degree sum to complete a generation is about 275 day-degrees above 7.5°C. Using some of the sets of weather data provided for the AHDB Pest Bulletin in 2016 and assuming moths laid their first eggs on 1 June then the second generation would be expected to begin in early to mid July (Table 3.11) which was broadly in line with the information available from trap captures (Figure 3.44).

Table 3.11. Estimated start of second generation of diamond-back moth (275D° above a threshold of 7.5°C from 1 June 2016)

Region	Estimated start for second generation (275D° above a threshold of 7.5°C from 1 June 2016)
Cornwall (Newquay)	13 July
Kent (Sittingbourne)	7 July
Suffolk (Woodbridge)	8 July
Wellesbourne (Warwick)	6 July
Norfolk (Norwich)	10 July
South Lincolnshire (Boston)	8 July
Nottingham (Billsthorpe)	10 July
Lancashire (Ormskirk)	9 July
York (Market Weighton)	10 July
Scotland (Blairgowrie)	18 July

Turnip moth

2015

Two Trapview traps were run at G's in 2015 and it was possible to compare the catches from these traps with the data from 13 Funnel traps (Figure 3.50). Not all of the Funnel traps were run over the full period, but even so they give a clear indication of the pattern of activity - with two distinct adult generations. The data from the two Trapview traps are at the front of the graph in blue and red and captured relatively low numbers of moths compared with some of the funnel traps.

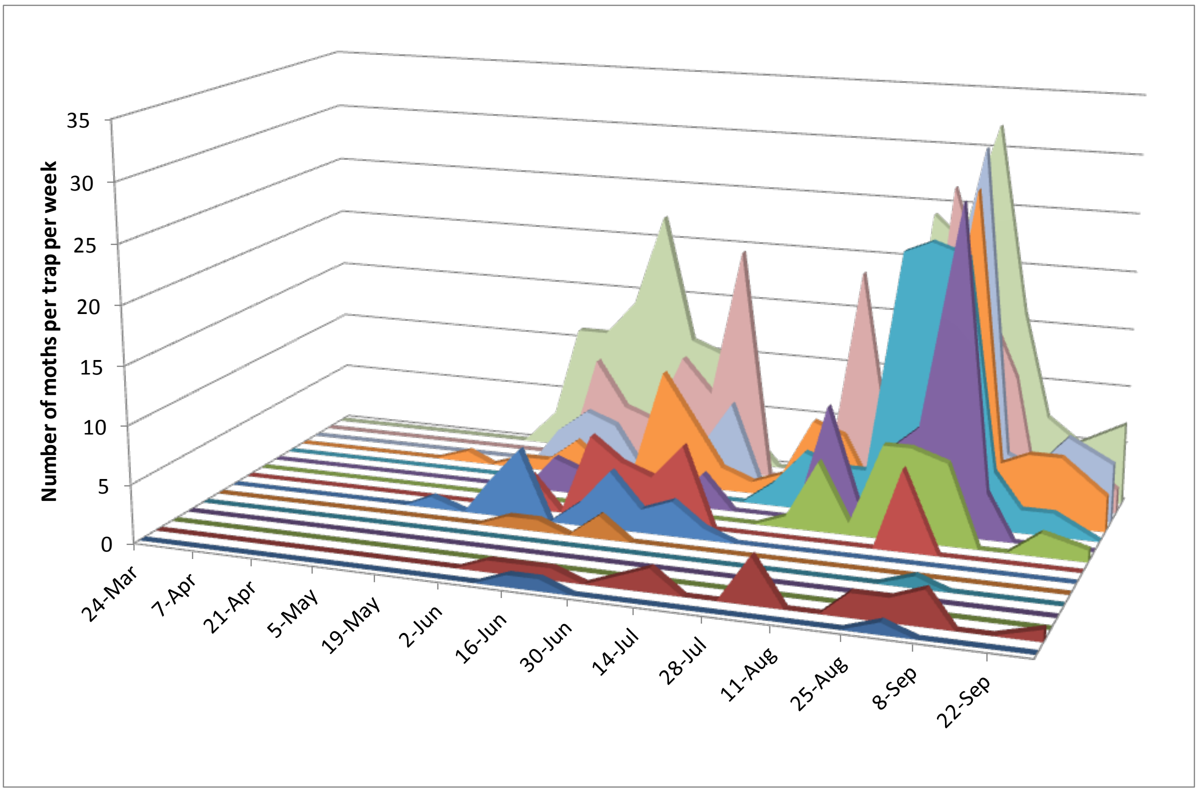


Figure 3.50. The numbers of turnip moths captured in 2 Trapview traps and 13 Funnel traps in 2015 in Cambridgeshire and Norfolk. The data from the two Trapview traps are at the front of the graph in blue and red.

2016

Two Trapview traps were again run at G's in 2016 but only captured 10 moths in total. The captures made by 5 Funnel traps are shown in Figure 3.51**.**

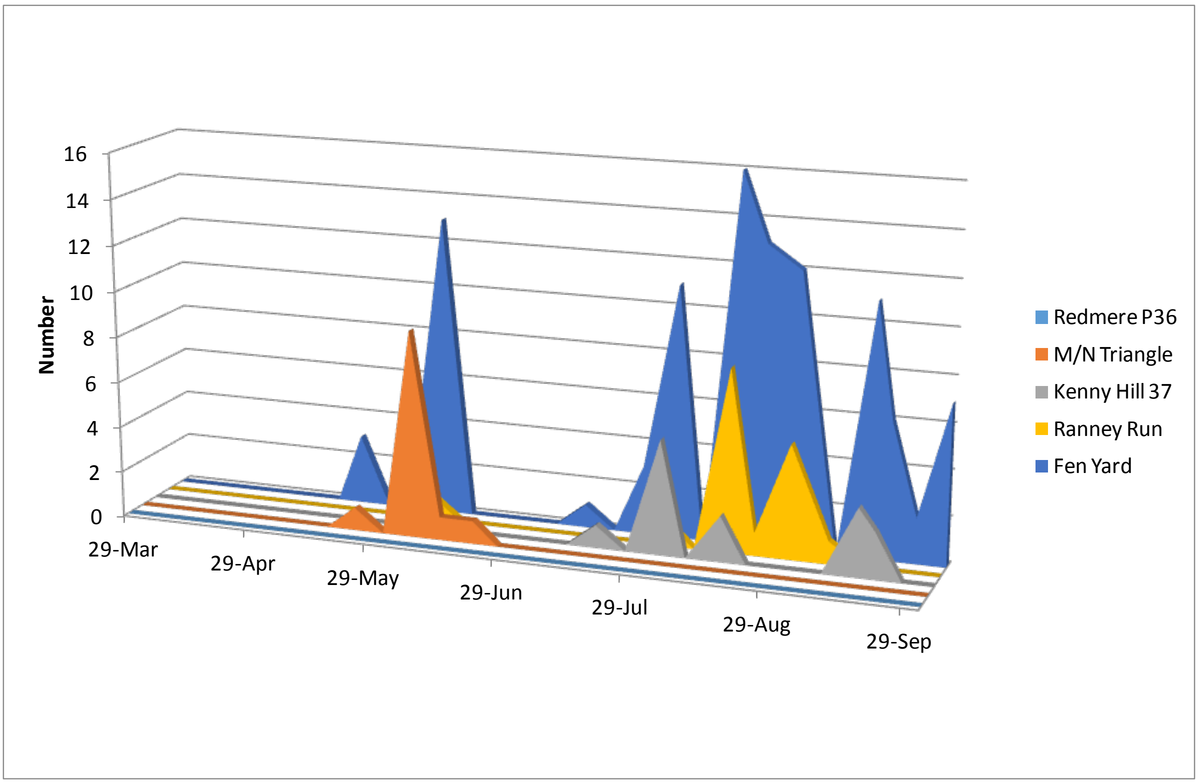


Figure 3.51. The numbers of turnip moths captured in 5 Funnel traps in 2016 in Cambridgeshire and Norfolk.

Other monitoring and control mechanisms

Objective 6 Investigate other monitoring and control mechanisms which may be effective and make recommendations for how they might be developed through future research.

The focus of this objective was on decision-support rather than all control methods *per se*.

Information from social media/citizen science

In the UK there are a number of entomologists (amateur and professional) who monitor moth activity, mainly using light traps. In recent years some of them have been reporting captures of moths (particularly the more unusual species) on web sites and social media e.g. Twitter. There is one Twitter account in particular that is focused on migrant Lepidoptera (Migrant Lepidoptera @MigrantMothUK). In summer 2016 a summer student based at the University of Warwick searched Twitter for reports of diamond-back moth and silver Y moth in the UK. It is possible to semi-quantify the information and also in most cases to it relate to a geographical location (town or similar). Figure 4.1 shows the numbers of silver Y moths per day reported on Twitter in 2016. Numbers were particularly high on 23-24 June and Table 4.1 shows that the moths were seen in several locations in southern England.

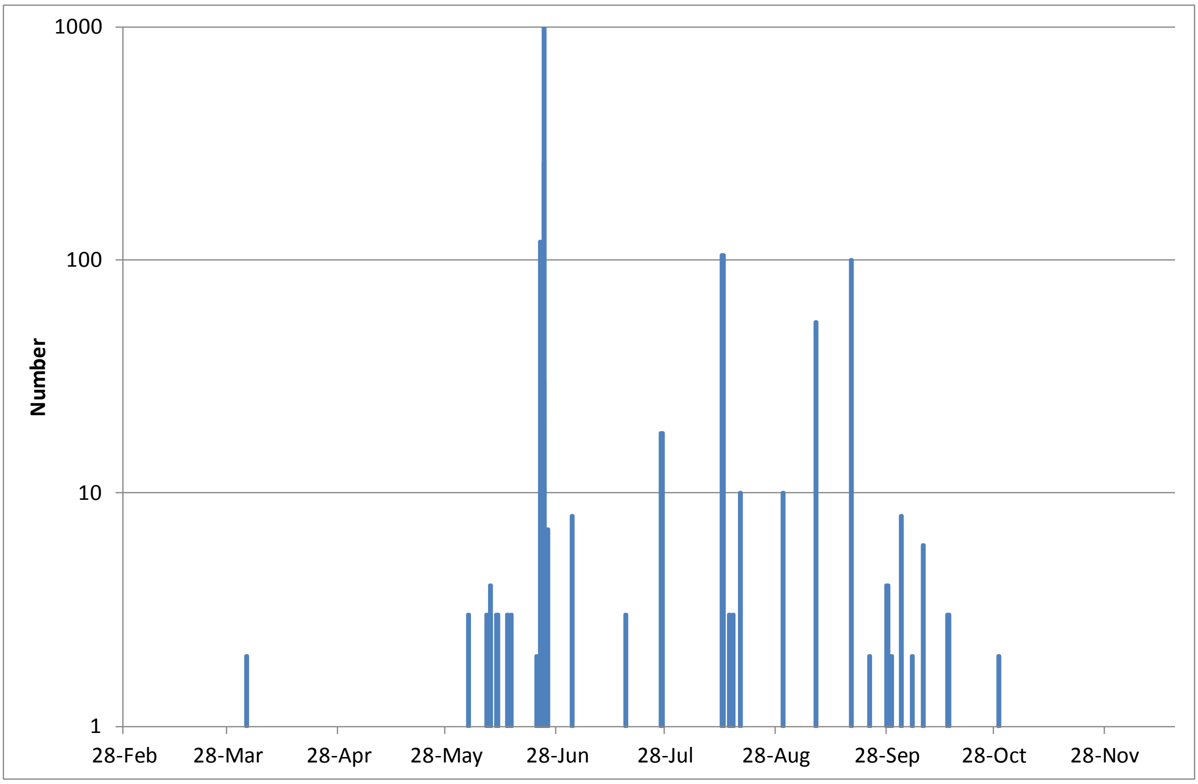


Figure 4.1. The numbers of silver Y moths per day reported on Twitter in 2016.

Table 4.1. Reports of silver Y moths on Twitter on 23-24 June 2016.

Date	**Estimated number**	Location	
23/06/2016	120	Landguard Butts	Suffolk
23/06/2016	2	Portland	Dorset
23/06/2016	10	Bonchurch, IoW	Isle of Wight
23/06/2016	4	Highworth, Wiltshire	Wiltshire
23/06/2016	2	Banstead, Surrey	Surrey
24/06/2016	1	Kiplingcotes	Yorkshire
24/06/2016	263	Ashdown	
24/06/2016	>1000	Oxford Marshes	Oxford
24/06/2016	>30	Felixstowe, Suffolk	Suffolk
24/06/2016	21	Hythe	Hythe
24/06/2016	4	Portland	Portland
24/06/2016	>30	East Wittering	Sussex

A particularly large ‘infestation’ of silver Y moths was seen at the Euro Finals in Paris on 10 July and these were expected to move to the UK. However, there was no evidence from any of the monitoring activity that they did this in significant numbers.

Figure 4.2 shows the numbers of diamond-back moths per day reported on Twitter in 2016. Very large numbers of moths were seen in different parts of the UK and reports on 31 May and 1 June are shown in Table 4.2.

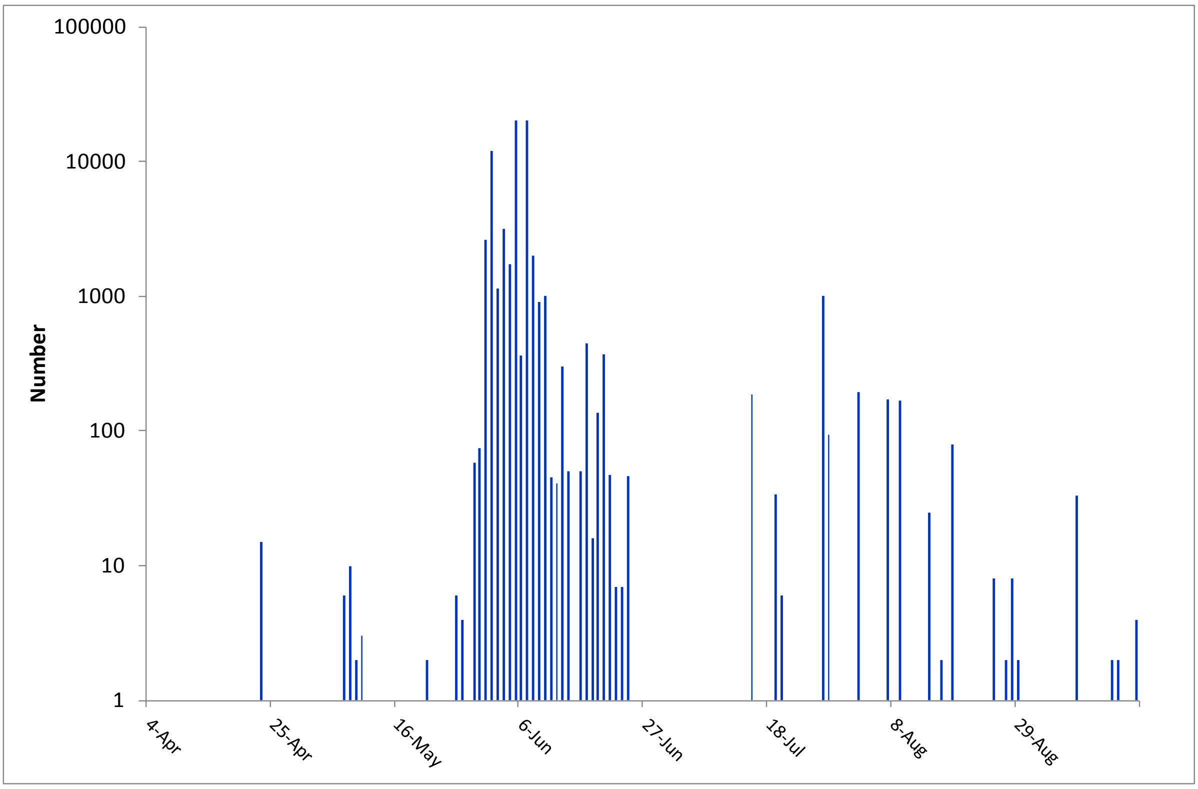


Figure 4.2. The numbers of diamond-back moths per day reported on Twitter in 2016.

Table 4.2. Reports of diamond-back moths on Twitter on 31 May – 1 June 2016.

Date	Estimated number	Location
31/05/2016	20 +	Attleborough-Tibenham
31/05/2016	50 +	Hemsby, Norfolk
31/05/2016	1 +	Norwich
31/05/2016	5 +	Hull Valley
31/05/2016	1	Cotswolds
31/05/2016	1	East Cornwall
31/05/2016	3	Offord D'Arcy, Cambridgeshire
31/05/2016	4	Dingestow
31/05/2016	8	Portland
31/05/2016	13	Longhope, Orkney
31/05/2016	18	Norwich
31/05/2016	c. 20	Norwich
31/05/2016	23	Offord D'Arcy, Cambridgeshire
31/05/2016	34	Offord D'Arcy, Cambridgeshire
31/05/2016	57	Horsham, West Sussex
31/05/2016	73	Ashford, Kent

31/05/2016	91	Tynemouth
31/05/2016	120	North Elmham
31/05/2016	175	Minsmere, Suffolk
31/05/2016	175	Newhaven, Sussex
31/05/2016	598	Eccles
31/05/2016	2630	Hemsby, Norfolk
01/06/2016	12000 +	Hemsby, Norfolk
01/06/2016	100 +	North east Norfolk
01/06/2016	50 +	Leicestershire
01/06/2016	74 +	Shropshire
01/06/2016	150-200	Yorkshire
01/06/2016	c.20	Gloucestershire
01/06/2016	5	Derbyshire
01/06/2016	15	Darley Dale, Matlock, Derbyshire
01/06/2016	25	Weymouth
01/06/2016	25	Somerset
01/06/2016	29	Kent
01/06/2016	41	Seabrook
01/06/2016	46	Walmer Bridge, Lancashire
01/06/2016	82	Carlton Colville, Suffolk
01/06/2016	97	North Warwickshire
01/06/2016	100s	Spurn peninsula
01/06/2016	100	Whitstable
01/06/2016	100s	Rudry Common
01/06/2016	106	South Birmingham
01/06/2016	123	Boreham, Essex
01/06/2016	135	North Elmham
01/06/2016	135	Sandwich
01/06/2016	138	Newhaven, Sussex
01/06/2016	175	Newhaven, Sussex
01/06/2016	176	Hythe
01/06/2016	183	Worcester
01/06/2016	210	Ispwich, Suffolk
01/06/2016	218	Horsham, West Sussex
01/06/2016	250	Hindolveston, Norfolk
01/06/2016	320	Boreham, Essex

01/06/2016	383	Portland
01/06/2016	450	Ryton Pools, Warwickshire
01/06/2016	500	Stonelees, Kent
01/06/2016	526	Strumpshaw
01/06/2016	1000s	Norfolk
01/06/2016	1000	Sheringham and Riddlington, North Norfolk
01/06/2016	1200	Norfolk
01/06/2016	1250	North Ferriby, East Yorkshire

Meteorological analysis of Autographa gamma and Plutella xylostella records in the UK during the 2015 and 2016 growing seasons

Silver Y (Autographa gamma)

In order to study the distribution and migration of the silver moth during 2015, three data sources were used. These are described in more detail below.

The first dataset was from the network of pheromone camera traps (Trapview) used for this project, specifically targeting *Autographa gamma*, with data provided for May 1st - September 30th 2015 inclusive. The second dataset comprises records from the Rothamsted Insect Survey light trap network, provided for all of 2015. The Insect Survey light trap network is made up of 84 light traps, mainly located around the UK, with an additional couple of light traps overseas. The third dataset used was records from the entomological vertically-looking radar (hereafter VLR) operated at Rothamsted Research in Harpenden, Hertfordshire. The VLR is able to provide information about the airspeed, heading direction, altitude, and orientation of insects in flight. Although the VLR does not allow for direct species identification; for groups with certain notable flight characteristics that do not have other overlapping species in the UK, species information can be estimated with good likelihood. From previous studies using the VLR (e.g. Chapman et al. 2012, PNAS 2013), it has been determined that *A. gamma* make up most of the noctuid moths within the weight class 111-181 mg. As such, this mass filter is used and then the Rothamsted team select only records occurring between dusk and dawn to restrict data to that likely to contain only *A. gamma* actively undertaking migratory flights.

In order to see whether there was good correspondence between the timing of individuals being recorded via the light traps, camera traps, and the VLR, the Rothamsted team examined the total number of silver Y moths recorded via the three methods over the course of the spring and summer during 2015 (Figure 4.3).

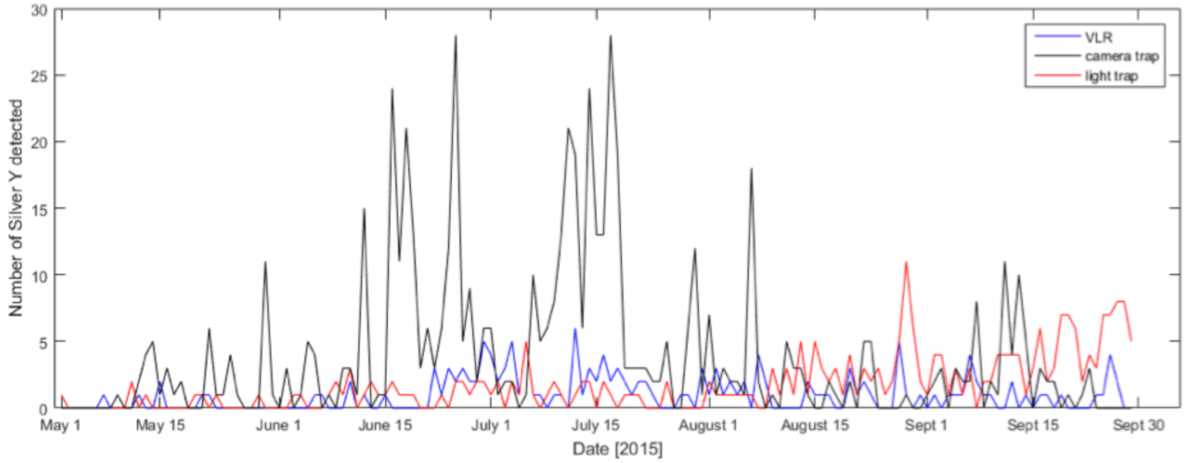


Figure 4.3. Occurrence of *A. gamma* throughout the 2015 season as recorded by the VLR (blue line; only migrating moths included), camera trap network (black line), and light trap network (red line) are shown.

The VLR and light traps indicated similar timing for the widespread movement of silver Y moths (Figure 4.3) while the camera traps recorded far greater numbers. However, the VLR data was restricted only to insects undertaking nocturnal migration at heights of 100 m or more, and so local movements are not included, while the camera traps likely represent more localised movement of silver Y moths at heights closer to crop levels.

Figure 4.4 shows the occurrence of silver Y moths throughout the 2015 season as recorded by the VLR (brown line; only migrating moths included) and light trap network (blue line) using only the four light traps that are closest to Rothamsted (all are within approx 40 km of the VLR). The timing matches quite well, although there are only a limited number of light trap catches. This would seem to suggest that the light traps are able to catch the moths quite soon after they migrate - possibly the same night or certainly the next day.

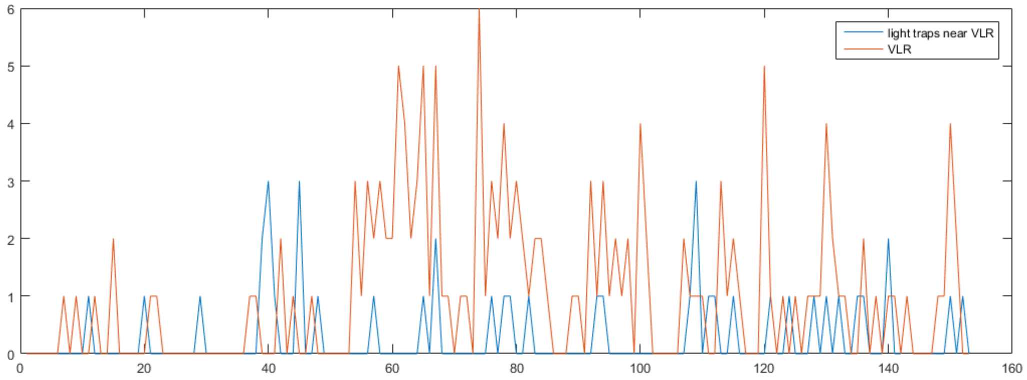


Figure 4.4. Occurrence of silver Y moths throughout the 2015 season as recorded by the VLR (brown line; only migrating moths included) and light trap network (blue line) using only the four light traps that are closest to Rothamsted (all are within approx 40 km of the VLR).

To study the meteorological conditions under which silver Y moths migrate the Rothamsted team plotted the wind field and temperature at 925 mb, generated by the NOAA NCEP reanalysis (details of how the reanalysis dataset is generated can be found Kalnay et al. 1996; the reanalysis data was accessed via:

https://www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis.pressure.html). The 925-mb pressure level was chosen as it best corresponds to the heights above ground level at which silver Y moths have been shown to migrate in previous studies using the Rothamsted VLR. The mean migration height has been shown to be close to 400 m (Chapman et al. 2013), with the lower and upper quartile bounds at 300 and 600 m. A video was prepared which plotted the records of silver Y moths from the light traps, camera traps, and VLR over the top of the wind and temperature data at 925 mb. From the video it was clear that that in many instances the moths are not caught in the camera traps until up to several days after their initial arrival, even for traps located close to the coast. For these coastal sites moths are often caught (in both the camera traps and light traps) when the wind direction was offshore and migration immediately preceding capture could not have been possible. In these situations, the Rothamsted team looked back at the synoptic conditions to see when the most likely time of arrival within the previous few days could have been and then used this date as a starting point for performing the back trajectories.

Back trajectory analysis was performed using the NOAA HYSPLIT READY model (available online at https://ready.arl.noaa.gov), with the meteorological fields populated with data from the NCEP reanalysis. HYSPLIT interpolates between pressure levels of the meteorological data, and so flight heights can be selected directly and are not constrained by the availability of corresponding pressure-level meteorological fields. For the back trajectory analysis, silver Y moth heights were constrained at 400 m above ground level, following Chapman *et al.*

(2013). Trajectory end-points were determined by comparing the moth location data to the prevailing synoptic winds and temperature as described above. For each of the back trajectories, it was assumed that the moths took off at sunset and migrated during the course of the night, landing around local sunrise. For the time period studied this generally gives flight times of 9 hours, with take-off between 20:00 - 21:00 and landing between 05:00 - 06:00.

The Rothamsted team investigated seven different arrival days indicated by trap catches, the VLR and the synoptic conditions. They tried to pick the days that represented those most likely to reflect actual migration from outside of the UK rather than local movements and compared the light trap and camera trap records from the south and east of the country with the wind field. They only completed back trajectories for those records which it seemed likely represented a wave of migration into the UK - so if there were several records on the same day or couple of days across a wider area, then they looked back to find if there were supportive winds for migration on the previous days. If there were then they completed the back trajectory. There were several records (from the light traps and the camera traps) that occurred following a period of unfavourable winds and so, since the Rothamsted team could not be sure of the date those moths had initially arrived, they did not calculate a trajectory for those records. The dates investigated were 8 May, 11 May, 14 May, 2 June, 11 June, 26 June and 10 July. The resulting back-trajectory maps are shown in Figure 4.5, indicating the source region for each flight as well as profiles of the flight height and corresponding temperature at flight level for each trajectory. The main source on these occasions appeared to be northern France.

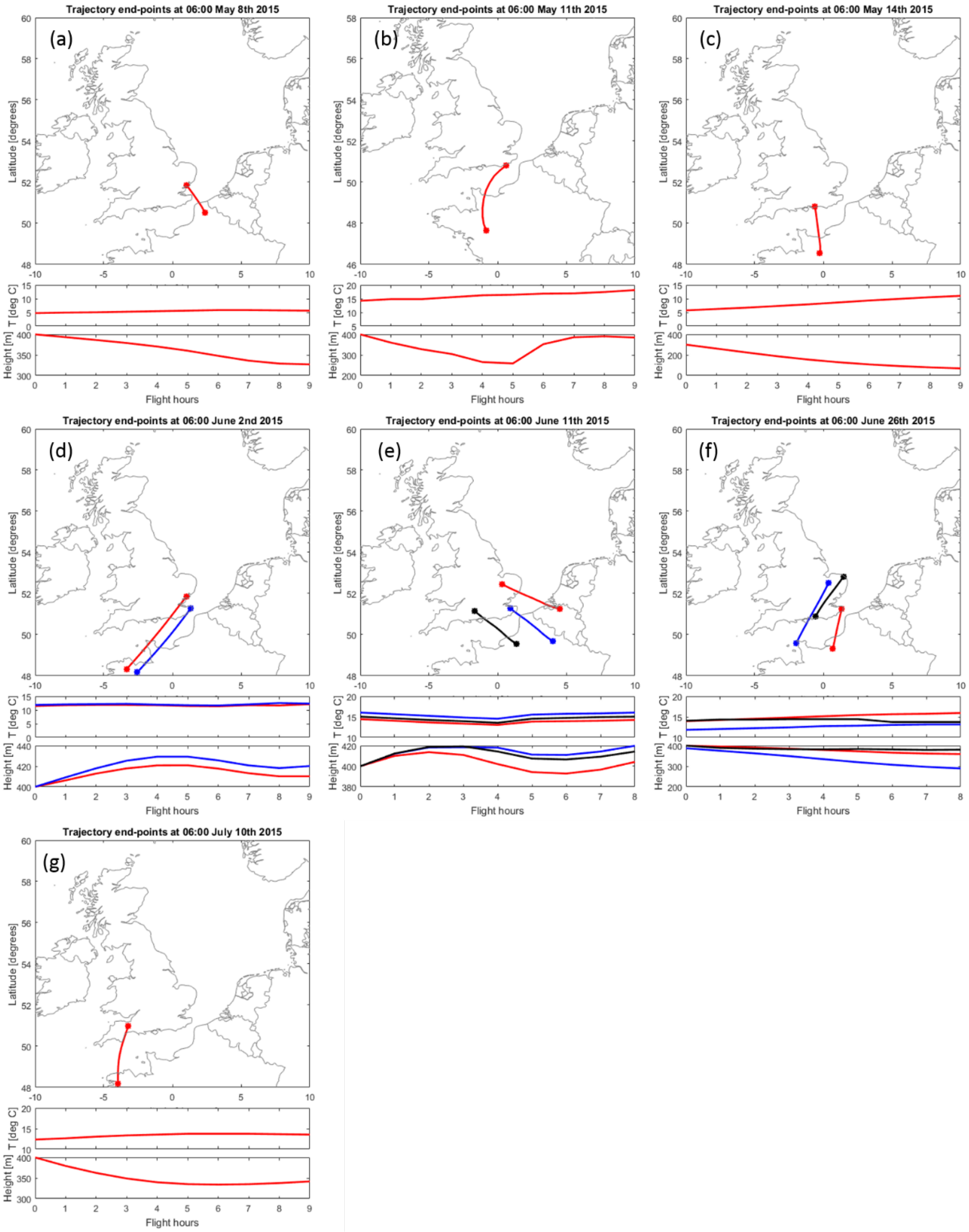


Figure 4.5. Back trajectories for selected records of silver Y moth occurrence from camera trap and light trap records. Each sub panel shows a map indicating the source and end locations of the trajectory and the route taken (top), with a plot of the temperature at flight height (middle) and the corresponding flight height (bottom). The source locations and dates for each panel are as follow: a) 8th May 2015, Great Bentley (51.85 N 1.018 E); b) 11th May 2015, Bosham, Sussex (50.82 N, -0.616 E); c) 14th May 2015, Bosham, Sussex (50.82 N, -

0.616 E); d) 2nd June 2015, Great Bentley (51.85 N 1.018 E), Sandwich, Kent (51.28 N, 1.338 E), Chelston, Somerset (50.983 N, -3.207 E); e) 11th June 2015, Ranney Run Plantation (52,457 N, 0.3107 E), Perry Wood (51.27 N, 0.923 E), Porton Down (51.144 N, -1.6826 E); f) 26th June 2015, Worth, Kent (51.257 N, 1.348 E), Wissy, Norfolk (52.531 N, 0.391 E), Ridlington, Norfolk (52.82 N, 1.476 E); g) Chelston, Somerset (50.983 N, -3.207 E).

Diamondback moths (*Plutella xylostella*)

Partway through the project, the Rothamsted team became aware of the unprecedented scale of the diamond-back moth outbreak that was occurring in the UK in 2016. With the agreement of other project partners, the project was expanded to study the migration of diamond-back moth during the 2016 season. Additional data sources were used to examine the movements of diamond-back moth, and these will be discussed below.

Accounts from observers, growers, and light trap operators on social media indicated the movements of extremely high numbers of diamond-back moth into the UK around 1 June 2016 (see Figure 4.6). Due to the small size of diamond-back moth (typical mass 1 - 4 mg, Chapman *et al.*, 2002) they can only be detected in the lowest gate of the VLR, which is centred on a height of 150 m. As such, the Rothamsted team focused on alternative data sources to study the movements and migration of diamond-back moth, focusing on the occurrence of the initial mass migration into the UK on 1 June 2016.

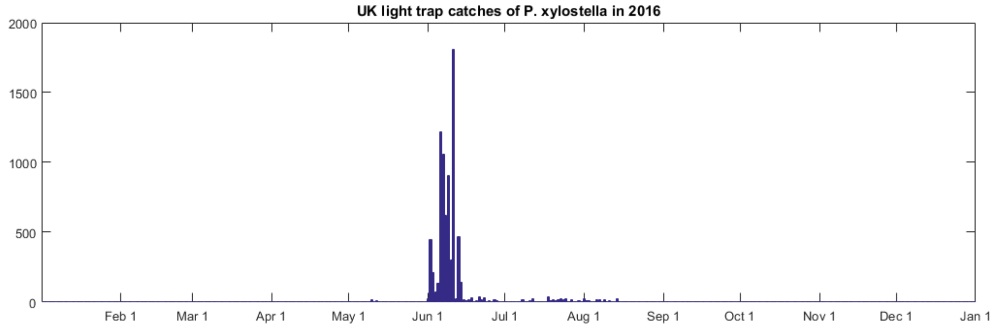


Figure 4.6. The number of diamond-back moth caught in light traps operated as part of the Rothamsted Insect Survey light trap network during 2016 (including all trap catches reported by 16 February 2017).

To track arrival within the UK, the Rothamsted team again relied on data from the Rothamsted Insect Survey light trap network. In order to see the initial spread of diamond-back moth from its' overwintering areas to higher latitudes across northern Europe, we made use of data from citizen science observation portals. These are websites on which observers and naturalists are able to upload lists of species that they have seen, complete with time and location data, and often with photographs. Many of these websites additionally link to smartphone apps so that people can submit data while out in the field, providing real-time observations with accurate GPS locations. Many European countries have their own moth or moth/butterfly portals, with some providing more general portals on which citizens can report species observations across multiple taxa at once. Some of these websites provide free access to their previous records, and so for those with open access portals we downloaded all the *P. xylostella* data from 2016. A list of the portals used, the countries covered, and the *P. xylostella* numbers recorded annually since 2000 is shown in Table 4.3.

Much of the yearly increase in numbers seen across all five countries in Table 4.3 is due to the steadily-increasing popularity of recording observations on these citizen science portals, and so the lower numbers in the early years reflect the recent expansion in citizen science data rather than true population increases. However, some trends are also visible in the data from the last five years, such as the sharp population decrease across all five countries in 2011-2012. After populations in northern Europe rebounding in 2013-2014, there is a steep decline in numbers recorded during 2015. Across all five countries, the numbers of diamond-back moth recorded in 2016 were the highest on record, with more than 1.2 million recorded in Belgium alone. Therefore, the numbers shown in Table 4.3 support the notion that 2016 saw diamond-back moth migration to northern European at levels unprecedented over the last decade.

Table 4.3. Numbers of diamond-back moth recorded on publicly-available citizen science databases across Northern Europe

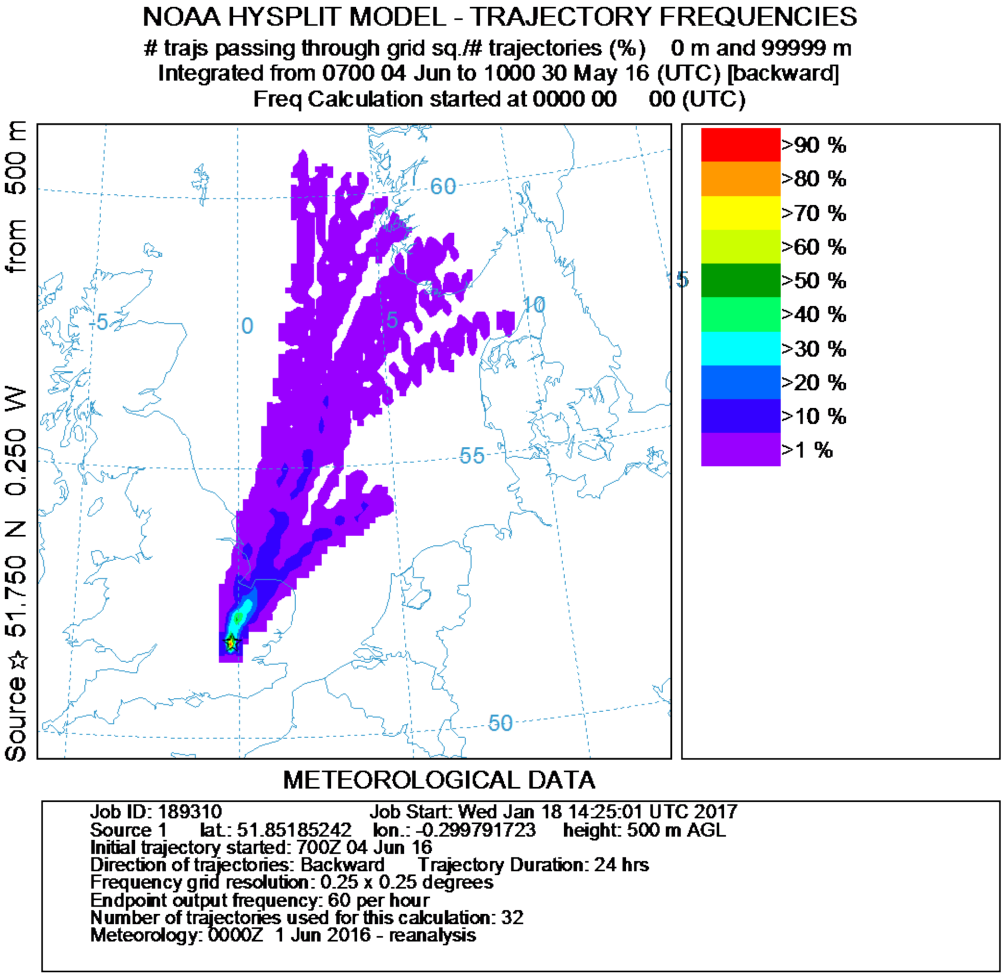
Year	**Norway** **http://www.artsobservasjoner.no**	**Sweden** **http://www.artportalen.se/**	**Finland** **https://laji.fi/**	**Belgium** **https://waarnemingen.be**	**Netherlands** **https://waarneming.nl**
2000	7	9	1241	89	0
2001	1	30	584	11	0
2002	6	27	328	47	0
2003	1	2	576	50	13
2004	2	4	109	18	1
2005	0	5	629	16	0
2006	0	13	355	243	38
2007	1	166	5325	112	75
2008	5	22	102	114	145
2009	679	1594	4820	11530	3342
2010	205	1732	8827	1137	1478
2011	39	178	668	236	333
2012	74	278	3004	1136	776
2013	2406	5610	29429	1615	2719
2014	4574	5068	17116	7793	10800
2015	382	450	3047	1099	1194
2016	57596	512467	25183	1206065	371861

As with the silver Y moth records from the light trap, the Rothamsted team used the diamond-back moth records from the light trap network in the UK and the citizen science observations across northern Europe to study the movement across the continent and the conditions preceding the initial mass migration into the UK on 1 June 2016. Using the NCEP reanalysis temperature and wind fields, they plotted a video which overlaid the citizen science records on the meteorological data to illustrate the effects of the wind conditions on diamond-back moth movement. The video clearly showed that large-scale movements of diamond-back moth are mainly based on the prevailing wind conditions, with warmer temperatures also an indication that mass movement is likely to occur.

In order to test whether it was possible to identify the source location for the initial outbreak incursion of diamond-back moth into the UK on 1 June, the Rothamsted team again used the

HYSPLIT trajectory model. This time the model was used in frequency mode, which initializes a new trajectory from a single starting location every 3 hours for a user-defined number of days. This enables illustration of a broader picture of mass movement over longer time periods, and is helpful for instances when the flight limitations of an insect species or their preferential take-off conditions may be unknown. For the trajectory end-point, they used the location of a light trap in Kimpton, Hertfordshire, which recorded its’ first 2016 instance of diamond-back moth on 1 June, with 16 moths caught in the light trap on that night. Since it is presently unknown whether there is a delay between initial arrival in the UK and the appearance of the moths in light traps and in a field setting, trajectories were initialized every 3 hours from 07:00 on 4 June backwards to 10:00 on 30 May. A flight height of 500 m was used for the trajectory analysis, with a flight duration of 24 hours. Since the true flight duration and minimum survivable temperature or pressure for diamond-back moth have yet to be determined, it is also possible that higher flight heights may be utilised, which would allow the moths to travel even further in a given time period, due to the general increase in wind speed with height.

The resulting frequency diagram for the source location of Kimpton (51.851 N, 0.2997 W) is shown below (Figure 4.7). It is clear that the only trajectories that allow for movement of diamond-back moth into the UK from overseas are those originating over land areas (unless the maximum flight duration or other flight capability of diamond-back moth has been significantly underestimated). This suggests that the initial incursion into the UK originated from the Norwegian and Danish coastlines. This is somewhat surprising, given that there were significant numbers of diamond-back moth throughout the low countries during this whole period following a build-up of populations there from mid-May onwards, and the populations there would have a much shorter distance to cover in order to arrive at the UK coastline.



Job ID: 189310   Job Start: Wed Jan 18 14:25:01 UTC 2017
Source 1   lat.: 51.85185242   lon.: -0.299791723   height: 500 m AGL
Initial trajectory started: 700Z 04 Jun 16
Direction of trajectories: Backward   Trajectory Duration: 24 hrs
Frequency grid resolution: 0.25 x 0.25 degrees
Endpoint output frequency: 60 per hour
Number of trajectories used for this calculation: 32
Meteorology: 0000Z 1 Jun 2016 - reanalysis

Figure 4.7. Back trajectory frequency plot for a sample record of *P. xylostella* from a light trap in Kimpton, Hertfordshire (yellow star). The colours indicate the likelihood of each 0.25° × 0.25° grid cell being the initial source location for a trajectory ending at Kimpton every 3 hours from 10:00 on 30 May 2016 to 07:00 on 4 June 2016.

Given the surprising nature of this result, the Rothamsted team ran a series of corresponding forward trajectory models initialized by citizen science records reported in Belgium, the Netherlands, and Norway during the week preceding 1 June. The model parameters were kept the same as in the backward trajectory frequency plot described above and shown in Figure 4.7, but these trajectories were initialized in the source locations described in the figure caption and allowed to run forwards in time for 24 hours (rather than backwards as before). Thus each coloured point in Figure 4.8 represents the likelihood of a particle starting in the source location ending up within a given 0.25° × 0.25° grid cell. Figure 4.8, shows further evidence that migration between the Norwegian coastline and eastern and southern UK was possible with a 24-hour flight duration. The forwards trajectories with source locations in Belgium and the Netherlands (the lower two panels in Fig. 5) do not support movement into the UK from these regions due to the prevailing wind direction at that time providing support for movement in a southerly and south-easterly direction towards central France.

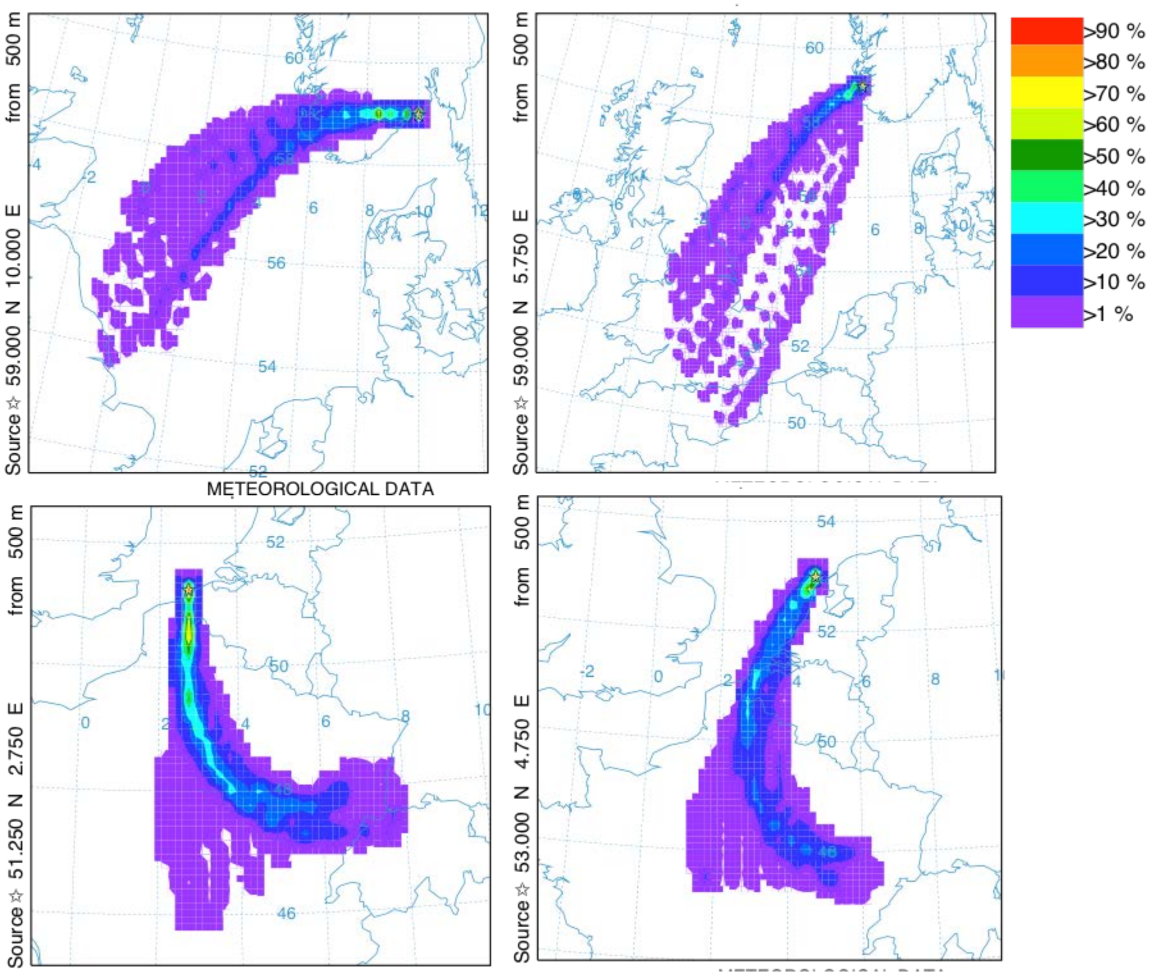


Figure 4.8. Forward trajectories from four starting locations in Norway (top left; source location 58.968 N, 9.905 E; top right; source location 59.002 N, 5.719 E), Belgium (lower left; source location 51.185 N, 2.82 E), and the Netherlands (lower right; source location 53.088 N, 4.795 E). The trajectories are started every 3 hours from 19:00 on 29 May 2016 to 19:00 on 31 May 2016 and flight height is set as 500 m with a 24-hour flight duration.

Knowledge and Technology Transfer

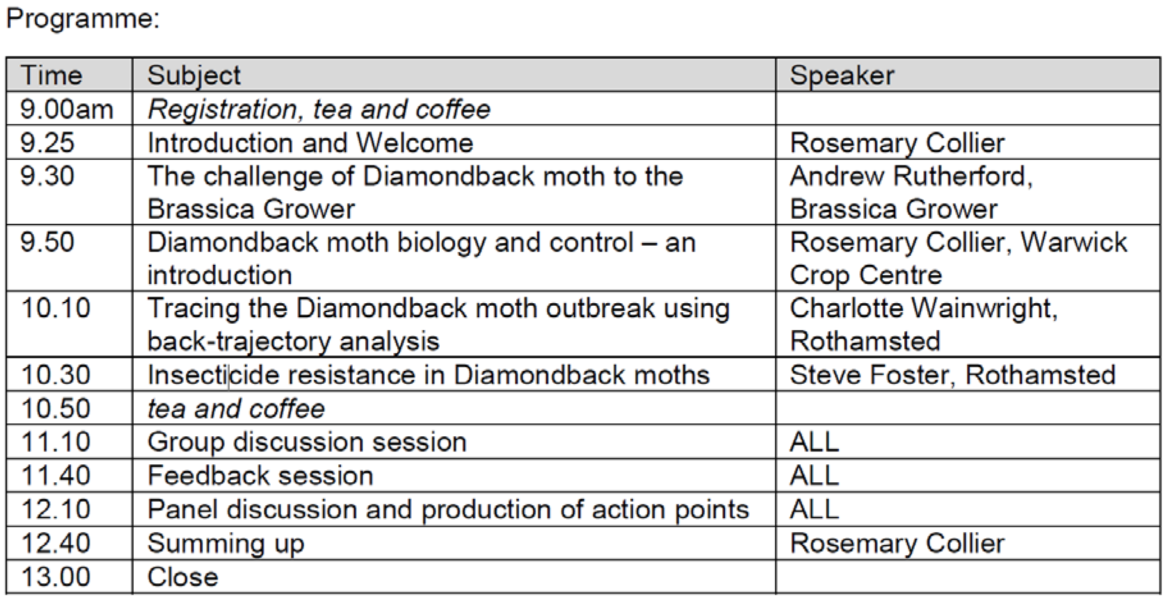
Objective 7 Engage and communicate with growers and other members of the industry

There were a number of communication activities associated with the project:

- Grower hosts of the Trapview traps were supported by Colin Carter and updated by email with an overview of the trap captures to date.
- **A workshop for the consortium was held at PGRO on 11th February 2016 and inlcuded presentations on the Trapview traps and on the biology of migrant Lepidoptera.**
- A workshop on diamond-back moth was held at PGRO on 24th January 2017 and an overview will be provided below.
- A presentation on the project was made at the Brassica and Leafy Salads Conference on 25th January 2017.
- Further presentations on the project were made at the Hutchinsons Vegetable Conference (22nd February 2017) and to the Boston & North Wash Training Group (27th February 2017) and the project was demonstrated at a University of Warwick, School of Life Sciences open evening.
- Information on diamond-back moth was supplied for the AHDB web site.
- Data collected in this project and the SCEPTRE project informed the successful AHDB application for a new 120 day EAMU (Extention of Authorisation for Minor Use) for 'Benevia 10OD' for use as an insecticide on Brussels sprout, broccoli, calabrese, cabbage and cauliflower for the control of diamond-back moth.

On 24th January 2017 the AHDB held a workshop to discuss the diamond-back moth invasion in 2017.

The programme was as follows:



Programme:

Time	Subject	Speaker
9.00am	*Registration, tea and coffee*	
9.25	Introduction and Welcome	Rosemary Collier
9.30	The challenge of Diamondback moth to the Brassica Grower	Andrew Rutherford, Brassica Grower
9.50	Diamondback moth biology and control – an introduction	Rosemary Collier, Warwick Crop Centre
10.10	Tracing the Diamondback moth outbreak using back-trajectory analysis	Charlotte Wainwright, Rothamsted
10.30	Insecticide resistance in Diamondback moths	Steve Foster, Rothamsted
10.50	*tea and coffee*	
11.10	Group discussion session	ALL
11.40	Feedback session	ALL
12.10	Panel discussion and production of action points	ALL
12.40	Summing up	Rosemary Collier
13.00	Close	

There were 3 breakout groups (loosely based around brassicas, baby leaf and other aspects) who addressed the following questions:

1. When did you first see DBM damage in your crops and for how long was DBM a significant problem?
2. Which crops were affected, was DBM more difficult to control in some crops than others?
3. Estimate on a crop by crop basis yield /% leaf damage over the period of damage caused by DBM
4. Do you monitor DBM numbers on a local basis using pheromone traps or other methods? – Were you aware of alerts on the DBM invasion (Pest Bulletin)?
5. What insecticides did you use, how did you use them and were they effective, do you use other controls e.g. insect mesh covers – did they work?
6. Are you aware of any new actives for control of larvae used around the world, which could be trialled here in the UK?

Key points from the workshop are summarised below:

When did you first see DBM damage in your crops and for how long was DBM a significant problem?

- Most growers did not see much damage before the large migration that began at the end of May 2016.
- In some places damage continued to occurred until September or even October.

- There is definitely something to explore with regard to the status of DBM in the south-west. It appears to overwinter there now, presumably on overwintered crops and thus may well be causing some damage late in the season.

Which crops were affected, was DBM more difficult to control in some crops than others?

- A range of crops were affected including cabbage, Brussels sprout, swedes, turnips, stocks.
- Less-affected crops were kale and baby leaf (the latter because of mesh covers to exclude *Scaptomyza*).

Estimate on a crop by crop basis yield /% leaf damage over the period of damage caused by DBM

- Swedes June to October. 5-10% reduction in volume
- Turnips 5-10%, edges/ends/breaks in mesh (deer a problem damaging nets)
- Lancashire – pointed cabbage 30% had to be trimmed back.
- Spalding – agree with above, where crop grew out of Verimark (cyazapyr)
- Brussels sprouts 20-40%, Broccoli not so much, floretting 20%, July/Aug/Sept out of problem
- South West 5% across the board – older leaves before use Verimark, cauli 5% damage on older leaves.
- 10% loss cabbage; 30% tenderstem; 100% florets; sprouts – drop in specifications-small.
- Leafy salads – small scale 1-2%.

Do you monitor DBM numbers on a local basis using pheromone traps or other methods? – Were you aware of alerts on the DBM invasion (Pest Bulletin)?

- Some growers use pheromone traps – but not all.
- Some feel that crop walking is sufficient.
- The Pest Bulletin is useful.
- Some thought the alerts were too late

What insecticides did you use, how did you use them and were they effective, do you use other controls e.g. insect mesh covers – did they work?

- Pyrethroid insecticides were ineffective due to insecticide resistance – identified by Rothamsted Research.
- Spinosad (Tracer) was effective as a foliar spray and there were also indications that drench applications (for cabbage root fly control) were effective (through systemic action) when treated plants were young.
- Indoxacarb provided some control.
- Diflubenzuron (Dimilin) also provided control.
- Bt did not work well on the whole. It needs to be applied in a way that gives good coverage.
- The diamides, chlorlantraniliprole (Coragen) and cyazypyr worked well. Coragen worked well on swedes. The Verimark drench treatment (for cabbage root fly control) controlled DBM on young plants and showed 8-10 weeks persistence (through systemic activity). The foliar spray Benevia (cyantranilipole) worked well.
- Mesh covers did not always work.

Are you aware of any new actives for control of larvae used around the world, which could be trialled here in the UK?

- No new conventional insecticides were suggested apart from next generation spinsosyns.
- Bioinsecticides including neem, *Beauveria bassiana, Isalia* (Bayer) and semiochemicals for mating disruption/lure and kill.
- Other approaches were rapeseed oil and LED light traps (used in Japan).

In addition to the workshop an on-line survey was undertaken using Survey Monkey and the questions and responses are summarised in Table 5.1. These responses supported the information gathered in the workshop.

Table 5.1. Questions and responses from on-line survey on diamond-back moth in commercial crops in 2016.

Question	**Summary of responses** **(13 respondents)**
Do you use pheromone traps to monitor diamond-back moth numbers in your brassica crops?	6 Yes and 7 No
If yes, when did you detect the migration (if at all)?	31 May - 9 June
When did you first observe eggs in your crops?	Late May - mid June - earlier in south-west
When did you first observe caterpillars in your crops	Late May - early July - earlier in south-west
Which crops?	All brassica crops
About how many caterpillars per plant?	1 to 40
Have you applied insecticides to control diamond-back moth?	13/13 - yes
If yes, which insecticides?	Pyrethroids, spinosad, indoxacarb, chlorantraniliprole, cyantraniliprole, Bt, Dipel
Have they been effective?	11/13 - yes
Where are your crops located?	South-west England - Scotland

Discussion

Insecticides and bioinsecticides

Silver Y moth

The trials to evaluate insecticides and bioinsecticides indicated some new insecticides with efficacy against silver Y moth. None of the bioinsecticides tested were effective, although Azadirachtin (SI2013-130) and another coded bioinsecticide showed efficacy in a laboratory trial in the SCEPTRE project (Table 1.2).

Diamond-back moth

Unfortunately no useful data were obtained from the field trial on diamond-back moth in 2015 and discussion at the consortium meeting indicated that laboratory and greenhouse trials might be the best way forward; one of each were completed successfully subsequently. These indicated some effective treatments including Lepinox Plus. The second trial using a population collected from the field in 2016 confirmed resistance to pyrethroid insecticides indicated by Steve Foster from Rothamsted Research. Although no experimental work was undertaken using turnip moth, some of the products tested may also be effective against this species.

Managing pest caterpillars

Both the silver Y moth and diamondback moth are migrant species that do not overwinter successfully in the UK. The turnip moth overwinters in the UK. Certain sets of historical data were available to the project from growers and from Rothamsted Research. Captures of silver Y moth made by the network of light traps run by the Rothamsted Insect Survey over the last 50 years in England and Wales and in Scotland showed that there is considerable variation in overall abundance from year to year. This was confirmed by the other sets of historical data on this species. The data on diamond-back moth highlighted the very large numbers which migrated into the UK in 2016. Some data for 1996 were also available and this was probably the last time relatively recently that very high numbers of diamond-back moths occurred. Data on turnip moth confirmed that there are two generations per year.

Captures by the Trapview traps were compared with ordinary traps (Funnel traps for the larger moths and Delta traps for diamond-back moth). In general, the Trapview traps were less effective. Some modifications were made to the traps in 2016 and in particular a trap that was modified to incorporate a funnel trap was more effective in capturing silver Y moths. There were a few other small technical problems that need addressing but the network functioned well and all trap hosts were able to view all the traps. Overall the traps indicated periods when moths were more abundant but within a region/locality there was considerable variation between locations in the numbers of moths captured. This may be related to the local distribution of moths and/or to the random nature of capturing moths in pheromone traps.

For silver Y moth, captures by all of the Trapview traps were summarised by county/region. Not all of the traps were fully operational in May each year but the figures show that moths were captured between May and October. There is no evidence that moths were captured earlier at sites that were further south or further east, for example.

For silver Y moth, attempts were made to relate infestations in crops to the numbers of moths captured in pheromone traps – in terms of timing and abundance. It is worth emphasising that as these were commercial crops they were subject to spray programmes which may have had an impact on infestations. Neither 2015 nor 2016 were years when silver Y moth caused major problems in salad crops. Whilst infestations usually followed periods of relatively high moth abundance in traps, there seems to be little scope to develop a threshold based on trap captures as the small number of sets of data available did not indicate that there would be a consistent relationship. Thus moth trap captures can only be used to warn of/highlight periods when egg-laying is likely to occur. Using the day-degree sum for egg hatch of silver Y moth of approximately 60 day-degrees above 7.7°C (estimated from published data) indicated that, for example, eggs laid on 14 June 2015 would hatch approximately 9 days later in Kent. This type of information might be a useful addition to the AHDB Pest Bulletin to help guide spray timings.

A study by Rothamsted Research on the origin of migrant silver Y moths indicated that in 2015 the major source on the occasions when possible flight paths were tracked (back-trajectory analysis) was northern France. There was also a suggestion that arrivals of moths were detected earlier by the entomological vertically-looking radar operated at Rothamsted Research in Harpenden, Hertfordshire and by light traps than by pheromone traps and it is possible that these moths require a short period to 'mature' following arrival before they are sexually active. At present the vertically-looking radar system is a research tool rather than a practical warning system and in the foreseeable future it is probably better to focus on information from the continent, from web sites, to provide an early warning

It seems likely that migrant diamond-back moths are sexually active and able to lay eggs as soon as they arrive. This is supported by the fact that after a very marked influx of moths at the end of May male moths were soon detected in pheromone traps although not in the very high numbers that would have been expected from such a large infestation. Data collected at Kirton in 1996 showed that eggs are being laid on crops at the same time that males are captured in pheromone traps. There was a perception by some growers (voiced at a workshop on 24 January and subsequently) that in 2016 there was a delay between moth arrival and egg-laying/development of the immature stages. However, the timing of what seems to be a clear subsequent generation ties in closely with the day-degree sum for development of eggs, larvae and pupae estimated from published data. Diamond-back moth eggs are very small and the very young larvae burrow into the plant tissues only becoming apparent as they grow, so they can be hard to detect rapidly in the field. In contrast, other growers thought that the moths were completing their life-cycle more rapidly than might be expected. The initial immigrants arrived over a period of a few days and some of them survived for some time after that, so this might have accounted for the belief that the life-cycle was extremely rapid. Information on the day-degree sums for completion of different stages in the life cycle of the diamond-back moth might be a useful addition to the AHDB Pest Bulletin.

The project has also highlighted the value of information available about migrant moths on web sites and social media. This was particularly useful in a second small study done by Rothamsted Research on the source of the large influx of diamond-back moths in 2016. Data from a number of web sites on the continent were used to indicate where infestations of diamond-back moth had been building. To test whether it was possible to identify the source location for the initial outbreak incursion of diamond-back moth into the UK on 1 June, the Rothamsted team used the HYSPLIT trajectory model to undertake back-trajectory analysis. This suggests that the initial incursion into the UK originated from the Norwegian and Danish coastlines. This is somewhat surprising, given that there were significant numbers of diamond-back moth throughout the low countries during this whole period following a build-up of populations there from mid-May onwards, and the populations there would have a much shorter distance to cover in order to arrive at the UK coastline. However, wind directions were not favourable at that time.

The study on the origins of the migrant moths led to some further questions:

- What were the meteorological conditions that caused the initial population explosion in continental Europe and where did the population overwinter in 2015-16?
- What were the early warning signs for the outbreak reaching the UK coast?
- Can we use citizen science and light trap data to forecast the probability of diamond-back moth movements reaching the UK in real time?

Recommendations for research

1. Given the promising results from the trajectory analysis, it is suggested that future efforts on this topic focus on testing the trajectory analysis in a real-time semi-operational framework. Since the citizen science data become available in near real-time, it may be possible to automate using the citizen science data as starting locations for forward trajectories and calculate the likelihood of an erruption of *P. xylostella* into the UK. This may enable the provision of short-term forecasts for pests arriving into the UK from mainland Europe and the possibility of a warning network. Should this prove feasible it could easily be extended to other similar pest species, provided that occurrence data is available from European partners. It is also suggested that there is an increased focus on partnering with counterpart European organizations, as in the event of a large movement of diamond-back moth into the UK these organizations may be able to link with growers in other countries who can provide information on which pest control methods have been

tried and their success, as well as the possibility of resistance profiling of European populations to give advance notice of the resistance profiles of populations which might arrive in the UK.

2. There is the potential to explore further novel methods of control for diamond-back moth including lure and kill or similar approaches using semio-chemicals. There is one UK company interested in this approach but the requirements for undertaking trials and subsequent registration need to be checked with CRD. There may be scope to undertake some of this work within the SCEPTRE+ project.
3. In the longer term there is the need to breed cultivars with resistance to diamond-back moth. Some further work to identify resistance traits is planned for the VeGIN project.
4. There is some question about the lack of efficacy of pheromone traps for diamond-back moth which possibly should be explored.

Subsequent activity

In May 2017 a web page was set up to provide growers with an overview of migrant moth activity in north-western Europe using information from citizen science web sites http://www2.warwick.ac.uk/fac/sci/lifesci/wcc/research/pests/plutella/sightings/. The web page has been highlighted in the AHDB Pest Bulletin and in AHDB communications and if large numbers of moths are detected then a warning will be issued.

Conclusions

Silver Y moth

- Trials have indicated several insecticides with efficacy against silver Y moth, some of which are novel products.
- Whilst infestations in lettuce crops usually followed periods of relatively high silver Y moth abundance, there seems to be little scope to develop a threshold based on trap captures as from the small number of sets of data available, there was not a consistent relationship. Thus moth trap captures can only be used to warn of/highlight periods of relatively high moth abundance when egg-laying is likely to occur, possibly together with information on days from egg-laying to egg hatch.
- A study by Rothamsted Research on the origin of migrant silver Y moths indicated that in 2015 the major source of moths on the occasions when possible flight paths were tracked (back-trajectory analysis) was northern France.

Diamond-back moth

- Trials indicated several novel products that are effective against diamond-back moth larvae, including the bioinsecticide Lepinox Plus (*Bacillus thuringiensis*). Benevia (cyazypyr) proved to be effective when used to control diamond-back moth in commercial brassica crops (permitted in summer 2016 as a result of a 120 day EAMU).
- Diamond-back moths can be captured in commercially-available pheromone traps and at present this is the best way to monitor crops for their presence, since eggs are so small and hard to find and newly-hatched larvae feed within the leaf tissue at first and are thus obscured from view.
- The initial incursion of diamond-back moths into the UK in 2016 appeared to originate from the Norwegian and Danish coastlines. It seems likely that migrant diamond-back moths are sexually active and able to lay eggs as soon as they arrive.
- There was a perception by some growers (at a workshop on 24 January) and subsequently that there was a delay between moth arrival and egg-laying/development of the immature stages of diamond-back moth. However, the timing of a subsequent generation (observed from trap catches and reports on Twitter) ties in closely with the day-degree sum for development of eggs, larvae and pupae estimated from published data.

All species

- A novel ‘remote’ monitoring system (Trapview) which uses a small camera located inside a pheromone trap to record moth captures daily shows promise as a method for monitoring the arrival of migrant caterpillar pests of salad and vegetable crops but requires some refinement, to increase moth captures in particular. The system needs to be improved so that a larger sample of moths is captured (relevant to all of the species considered in this project).
- The project has highlighted the value of information available about migrant moths on web sites and social media. The potential of this information is being explored during 2017.

Knowledge and Technology Transfer

There were a number of communication activities associated with the project:

- Grower hosts of the Trapview traps were supported by Colin Carter and updated by email with an overview of the trap captures to date.
- **A workshop for the consortium was held at PGRO on 11th February 2016 and inlcuded presentations on the Trapview traps and on the biology of migrant Lepidoptera.**
- A workshop on diamond-back moth was held at PGRO on 24th January 2017.
- A presentation on the project was made at the Brassica and Leafy Salads Conference on 25th January 2017.
- Further presentations on the project were made at the Hutchinsons Vegetable Conference (22nd February 2017) and to the Boston & North Wash Training Group (27th February 2017) and the project was demonstrated at a University of Warwick, School of Life Sciences open evening.
- Information on diamond-back moth was supplied for the AHDB web site.

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