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Project leader:	Rosemary Collier, University of Warwick
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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.

Rosemary Collier
Director, Warwick Crop Centre
University of Warwick

Signature .... Date ....

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GROWER SUMMARY

Headline

There are some very strong relationships between the timing of the spring and summer migrations by *Aphis fabae* and weather (temperature) data and these could be developed into a day-degree forecast to predict the timing of migration and also to predict the abundance of aphids in conjunction with real-time suction trap outputs.

Background

The black bean aphid (*Aphis fabae*) has a very large range of summer hosts, of which spinach is one. *Aphis fabae* overwinters mainly as eggs on spindle bushes, and a few other shrub species, and occasionally, in warmer locations, as mobile stages on members of the pea/bean family (wild hosts or winter beans). The eggs hatch from late February to early April and colonies develop on young leaves and shoots of the winter host. Winged forms are produced in May/June and these migrate to summer hosts. Reproduction continues throughout the summer, further winged forms are produced in response to crowding and these spread within crops and invade new crops. Populations usually peak in July/August. In autumn *A. fabae* migrates back to spindle and winter eggs are laid.

Winged forms of *Aphis fabae* are captured in the suction traps operated by the Rothamsted Insect Survey and information on numbers captured is presented on their web site. Several researchers have developed forecasting systems for infestations of *A. fabae* on beans or sugar beet. Some of these have relied on counting aphid eggs on overwintering hosts. However, a paper by Way *et al.* (1981) considered an approach using both egg counts and suction trap samples to forecast infestations in field beans. The forecasting system they developed was used in the UK for a number of years.

Previous studies on other pest species have indicated relationships between pest activity/abundance and weather data (either day-degree forecasts or statistical relationships). Rothamsted suction trap data and weather data could be summarised and analysed to determine whether there are any relationships that could be developed for *A. fabae*. The aim of this project is to gain a better understanding of *A. fabae* and its life cycle with a view to developing a prediction method to provide advance warning of possible sudden influxes onto spinach crops.

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Summary

The project consisted of four objectives:

Objective 1. Produce a short review of relevant information on the life cycle and biology of Aphis fabae and summarise previous approaches to forecast development.

A relatively small number of papers have been published on this topic and these were summarised. Researchers have divided captures by suction traps into three phases representing the spring migration from spindle to herbaceous hosts, the summer migration to other hosts and then the autumn migration back to spindle. Whilst the second and third phases are well-separated in time, the first phase can be hard to separate from the second when inspecting the data. The studies have indicated that:

1. Populations fluctuate from year to year and two studies indicated that there may be a 'pattern' to this e.g. regular alternation of small and large populations.
2. There may be correlations between the abundance of *A. fabae* and certain weather conditions (temperature or rainfall).
3. The distribution of winter and summer host plants determines the distribution of *A. fabae* and its relative abundance to a great extent. The distribution of the winter host, spindle, is not uniform and it is more abundant in the south and west than the east (it grows on calcareous soils) and this affects the distribution of eggs and thus the occurrence of spring migrants (few in Norfolk, Lincolnshire and northern Britain). The summer host crops are more abundant in other areas (such as East Anglia). However, since summer migrants occur in moderate numbers throughout the UK, even where the key crops are scarce or absent, it is apparent that wild hosts are also colonised.
4. It is possible to sample spindle trees during the winter to record the numbers of overwintering eggs. A paper by Way *et al.* (1981) described the use of egg counts and suction trap data to forecast the infestation of field beans by *A. fabae*. They found that:
    - Autumn trap catches (the autumn migration back to spindle) were useful as early forecasts of likely very large or very small populations of aphids on field beans (about 8 months later), but that otherwise they lacked precision.
    - Egg sampling in winter provided a more accurate forecast approximately 5 months before infestation of the bean crop.

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- In May, aphid counts on spindle were most useful for predicting the time of migration and provided approximately 2 weeks warning for insecticide application if needed.
- Captures in the suction traps in spring provided the latest estimate of both the sizes of crop infestations and the best timing for insecticide treatment.
- In terms of forecasting infestation levels, Way *et al.* used criteria as shown in the Table below.

Forecasting criteria for catches in suction traps (from Way *et al.*, 1981).

Forecast damage to spring-sown beans	Total aphids/trap (mid September – early November)	Total aphids/trap (May – mid June)
Unlikely	0-15	0-4
Possible/probable	>15	>4

Objective 2 Summarise Rothamsted suction trap records on captures of Aphis fabae over at least 10 years to indicate the pattern of aphid migration.

Rothamsted Research provided suction trap data for *Aphis fabae* captures at Broom's Barn in Suffolk and Wye in Kent. This was because the suction traps at these sites captured relatively large numbers of *A. fabae*. EXCEL was used to summarise the data in terms of aphid abundance and the timing of key events in the pattern of aphid migration. Linear regressions were fitted to some of the data and correlation coefficients were estimated using the facility in EXCEL. The total numbers of aphids captured up to 31 August (spring and summer migrations) in each year are shown in Figure A.

Generally, more spring migrants were caught at Wye than at Broom's Barn, whilst summer and autumn migrants were more abundant at Broom's Barn. Annual captures (up to 31 August) at Wye and at Broom's Barn were highly correlated, indicating a general effect of 'year' on abundance. There was a statistically significant correlation for the data from Broom's Barn between numbers of aphids trapped in spring (up to 15 June) and those trapped in the previous autumn, but no correlation for the data from Wye. There were no correlations between numbers of aphids trapped in summer (15 June – 31 August) and those trapped in the previous spring (up to 15 June).

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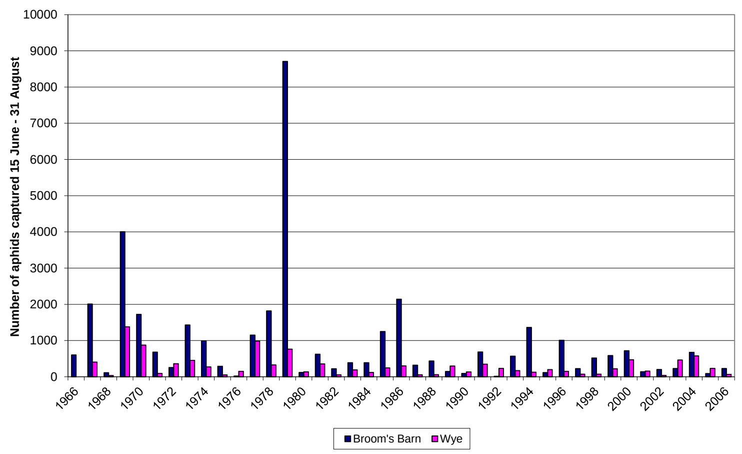

Figure A. Total numbers of female *A. fabae* captured per year at Broom's Barn and Wye over 40 years.

Both the times of first capture and 50% capture have become earlier during the 40 years of observations. The date of 50% capture was consistently earlier at Wye than at Broom's Barn, but the relationship was less consistent for the date of first capture.

Objective 3. Look for relationships between aphid flight times/abundance and weather data using information from the literature as available.

The information on key events and abundance from Objective 2 was used to look for relationships between key events, abundance and weather records (temperature and rainfall). Weather data for Suffolk and Kent were obtained from the Met Office web site and consisted of monthly averages for the maximum and minimum daily temperature and the total monthly rainfall for Lowestoft and Manston respectively. The mean temperature for defined periods in the spring was calculated and was used to determine the relationship between the date of first capture and 50% capture (up to 31 August) and mean temperature. The date of first capture was highly negatively correlated with all of the measures of mean temperature; the warmer the spring, the earlier the first aphid was captured (e.g. Figure B). The relationship for the two sites was also very similar, the fitted lines having similar slopes and intercepts.

The date of 50% capture was also highly negatively correlated with all of the measures of mean temperature and, as with the date of first capture, the warmer the spring, the earlier the date when 50% of aphids were captured. The fitted lines for the two sites were also very similar. Relationships between temperature or rainfall and aphid abundance were also investigated but there were no significant correlations.

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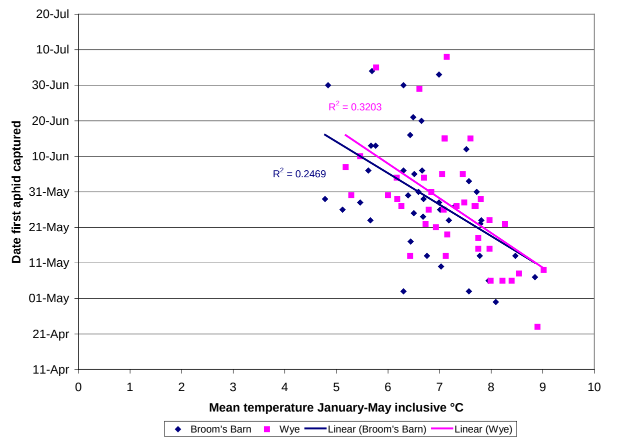

Figure B. Relationship between the date the first aphid was captured and the mean temperature in January-May inclusive.

Objective 4. Propose a way forward

This analysis was obviously limited, firstly because only data from two suction trap sites were used and secondly because the weather data sets were not from sites that were particularly close to the suction traps, nor were daily records available. Thus the data can be used only to indicate trends that can be used to suggest a way forward.

The analysis has not detected any obvious strong relationships with either temperature or rainfall, unlike previous studies. This may be because the temperature and rainfall parameters used in this project are too crude (because no daily records were available), the weather records were from sites too remote from the suction traps, or because the statistically significant relationships in the other studies occurred by 'chance', being based on smaller sets of data where the specific weather patterns favoured particular correlations (e.g. two studies observed cycling in population size and this is not obvious from the larger data sets used in this study (Figure A)).

The timing of migration of winged aphids also varies from year to year and site to site, but in this case there is a very strong correlation with the mean temperature summarised over different periods leading up to the spring and summer migrations. The high correlation coefficients and the similarity of the fitted lines for the two sites (slope and intercept) indicate that there is a robust relationship with temperature and that the timing of key events should be highly predictable using accumulated temperatures (day-degrees). Such day-degree forecasts have been used successfully for other pest aphids that overwinter as eggs on woody hosts (e.g. willow-carrot aphid, lettuce root aphid – used on the HDC Pest Bulletin).

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Based on the findings of Objective 2 and Objective 3, a way forward is proposed:

1. Obtain data for all suction trap sites at which reasonable numbers of *A. fabae* have been captured.
2. Obtain comparable daily weather data from appropriate Met Office stations.
3. Use the suction trap data and weather data to develop a day-degree forecast for *A. fabae* to predict the start of the spring migration and the timing of different stages of the summer migration (i.e. when 1% caught, 10% caught, 50% caught, 90% caught etc).
4. Analyse these data for relationships that might help to predict abundance.
5. Develop a method of predicting abundance in the summer as early as possible from real-time suction trap data. This is probably feasible by using day-degrees to predict, for example, the date of 10% capture and then checking the real-time suction trap data to see how many aphids 10% capture equates to. This can then be used to predict abundance going forwards.
6. Determine whether relationships developed by Way *et al.* (1981), based on the numbers of aphids captured in suction traps, are likely to be of any practical use to spinach growers.
7. Incorporate the forecast into the HDC Pest Bulletin

Financial Benefits

This proposal is in direct response to a request from industry and the intention is to provide information that will inform an improved control strategy for *Aphis fabae* on spinach.

Action Points

- Even without the development of a forecast, growers could regularly update themselves on the numbers of *A. fabae* captured by Rothamsted suction traps in the current season http://www.rothamsted.ac.uk/insect-survey/STAphidBulletin.php.

- To reinforce this, information on suction trap catches could be added to the HDC Pest Bulletin updates.

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SCIENCE SECTION

Introduction

The black bean aphid (*Aphis fabae*) has a very large range of summer hosts, of which spinach is one. The principal host crops involved are field beans, broad beans and sugar beet, as well as most forms of garden bean. Some common wild hosts include dock, poppies, goosefoot and fat hen.

Aphis fabae overwinters mainly as eggs on spindle bushes *(Euonymus europaeus*), and a few other shrub species, and occasionally, in warmer locations, as mobile stages on members of the pea/bean family (wild hosts or winter beans). The eggs hatch from late February to early April and colonies develop on young leaves and shoots of the winter host. Winged forms are produced in May/June and these migrate to summer hosts. Reproduction continues throughout the summer, further winged forms are produced in response to crowding and these spread within crops and invade new crops. Populations usually peak in July/August. In autumn *A. fabae* migrates back to spindle and winter eggs are laid (Rothamsted Research, 2012).

Winged forms of *A. fabae* are captured in the suction traps operated by the Rothamsted Insect Survey. Figure 1 shows the weekly total numbers of *A. fabae* captured in the suction trap at Broom's Barn in Suffolk in 2011.

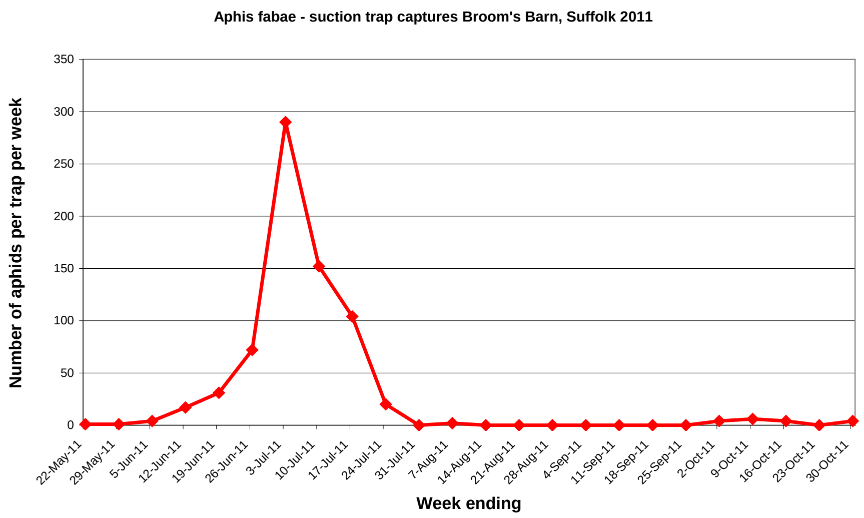

Figure 1. Numbers of *Aphis fabae* captured in the Rothamsted suction trap at Broom's Barn in 2011 (Data from Rothamsted Research).

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Several researchers have developed forecasting systems for infestations of *A. fabae* on beans or sugar beet. Some of these have relied on counting aphid eggs on overwintering hosts. However, a paper by Way *et al.* (1981) considered an approach using both egg counts and suction trap samples to forecast infestations in field beans. They concluded that information on the spring migration from spindle and also the autumn migration back to spindle was useful. The forecasting system they developed was used in the UK for a number of years.

Previous studies on other pest aphid species have indicated relationships between pest activity/abundance and weather data (either day-degree forecasts or statistical relationships). The aim of this project was to determine whether this approach would be feasible for *A. fabae*.

The project consisted of four objectives:

Objective 1 Produce a short review of relevant information on the life cycle and biology of *Aphis fabae* and summarise previous approaches to forecast development.

Objective 2 Summarise Rothamsted suction trap records on captures of *Aphis fabae* over at least 10 years to indicate the pattern of aphid migration.

Objective 3 Look for relationships between aphid flight times/abundance and weather data using information from the literature as available.

Objective 4 Propose a way forward

The report is structured by objective.

Materials and methods

Objective 1. Produce a short review of relevant information on the life cycle and biology of Aphis fabae and summarise previous approaches to forecast development.

A relatively small number of papers have been published on this topic. These were accessed and the key papers are summarised below.

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Objective 2. Summarise Rothamsted suction trap records on captures of Aphis fabae over at least 10 years to indicate the pattern of aphid migration.

Rothamsted Research (Richard Harrington) provided the suction trap data for *Aphis fabae*. It was agreed that this project would focus on a sub-set of the data (from 2 sites). The sites selected were Broom's Barn in Suffolk and Wye in Kent. This was because the suction traps at these sites captured relatively large numbers of *A. fabae* and because there were long runs of data (41 years for Broom's Barn and 40 years for Wye). The data were provided in an EXCEL spreadsheet and EXCEL was used to summarise the data in terms of aphid abundance and the timing of key events in the pattern of aphid migration. Information on numbers captured is presented as '*Aphis fabae* gp.' as it is hard to distinguish between different forms. In addition, male *A. fabae* cannot be distinguished from other species of *Aphis*.

Linear regressions were fitted to some of the data and correlation coefficients were estimated using the facility in EXCEL. The correlation coefficients were based on data sets with between 35 and 40 degrees of freedom. Table 1 summarises the correlation coefficients r and r^2 for 35 degrees of freedom for p values of 0.05, 0.01 and 0.001. Lines where r^2 is equal to or greater than one or more of the values shown indicate statistically significant relationships.

	r (correlation coefficient)	r^2 (shown on graphs)
P=0.05	0.325	0.106
P=0.01	0.418	0.175
P=0.001	0.519	0.269

Objective 3. Look for relationships between aphid flight times/abundance and weather data using information from the literature as available.

The information on key events and abundance from Objective 2 was used to look for relationships between key events, abundance and weather records (temperature and rainfall). Weather data for Suffolk and Kent were obtained from the Met Office web site and consisted of monthly averages for the maximum and minimum daily temperature and the total monthly rainfall for Lowestoft and Manston respectively. Manston is approximately 25 miles from the suction trap at Wye and Lowestoft is approximately 60 miles from the suction trap at Broom's Barn.

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Objective 4. Propose a way forward

Based on the findings of Objective 2 and Objective 3, a way forward was proposed.

Results

Objective 1. Produce a short review of relevant information on the life cycle and biology of Aphis fabae and summarise previous approaches to forecast development.

Aphis fabae overwinters mainly as eggs on spindle bushes *(Euonymus europaeus*), and a few other shrub species, and occasionally, in warmer locations, as mobile stages on members of the pea/bean family (wild hosts or winter beans). The eggs hatch from late February to early April and colonies develop on young leaves and shoots of the winter host. Winged forms are produced in May/June and these migrate to summer hosts. Reproduction continues throughout the summer, further winged forms are produced in response to crowding and these spread within crops and invade new crops. Populations usually peak in July/August. In autumn *A. fabae* migrates back to spindle and winter eggs are laid (Rothamsted Research, 2012). It is not clear why the numbers of aphids captured in suction traps decline between the peak in July/August and the autumn migration (numbers may still be increasing on plants) but this may be another example of the 'aphid crash' (Karley *et al.*, 2004). Karley *et al.* concluded that ecological factors causing the mid-season population crash include a decline in plant nutritional quality, increased natural enemy pressure as the season progresses and extreme weather events (although these do not occur every year). The crash (as seen on host plants) may also be the result of enhanced emigration and/or reduced birth rates. Indeed, the size and timing of the crash may influence the number of sexual aphids produced in the autumn (Karley *et al.*, 2004).

Researchers have divided captures by suction traps into three phases (see Figure 2.1), representing the spring migration from spindle to herbaceous hosts, the summer migration to other hosts and then the autumn migration back to spindle (Way *et al.*, 1981). Whilst the second and third phases are well-separated in time, the first phase can be hard to separate from the second when inspecting the data.

In a very early study, experiments for nine successive years (Way, 1967) showed that *A. fabae* populations on field beans sown in mid-March were either 1) large with peak densities between late June and mid-July or 2) very small with peak densities in early August. Way concluded that the largest populations developed when many plants had been colonized by spring migrants from spindle and when temperatures and radiation were above average

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during June and early July. In contrast, cold, dull weather slowed multiplication and decreased the size of the summer population, even when there were a large number of colonizers initially. Way also suggested that the summer population could be smaller than might be predicted (from the numbers of spring colonizers) when natural enemies were exceptionally abundant in early June.

Way (1967) also observed that small and large early summer populations tended to alternate in successive years, and there was similar evidence of cycling in population size in a later study by Thacker *et al.* (1997). However, Way considered that the alternation could be upset by hot, sunny weather during July and August (and possibly also September and October) which compressed the population cycle.

Cammell *et al.* (1989) concluded that the distribution of winter and summer host plants determines the distribution of *A. fabae* to a great extent. At the time of their study, sugar beet was the main summer host, but the authors suggested that other hosts and particularly weeds such as fat hen (*Chenopodium album*) were important – a conclusion reached because autumn migrants were captured in traps that were located beyond the area where the main host crops (sugar beet and beans) were grown.

The distribution of the winter host, spindle, is not uniform and it is more abundant in the south and west than the east (it grows on calcareous soils) and this affects the distribution of eggs and thus the occurrence of spring migrants (few in Norfolk, Lincolnshire and northern Britain). Cammell *et al.* (1989) observed that the situation changed following the spring migration, as beans (an important summer host) were grown mainly in the East. Therefore, in terms of the total number of colonised plants per unit area, most aphids occurred subsequently in East Anglia, especially Essex. This indicated that a greater proportion of spring migrants colonized beans successfully in the East where the crop was most abundant. The numbers of spring migrants colonizing beans and the subsequent size of the population were positively correlated (Way & Cammell, 1973) and this was reflected in the large numbers of summer migrants in the East.

Sugar beet was, and still is, grown in the East and the largest populations of *A. fabae* on unsprayed sugar beet were in this area (Cammell *et al.*, 1989). The size of the summer migration of *A. fabae* reflected closely the combined areas of bean and sugar beet crops, but especially sugar beet, which was more common. However, since summer migrants occurred in moderate numbers throughout the UK, even where these `crops were scarce or absent, it was apparent that wild hosts were also colonized. The summer migrants were

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more abundant than the spring migrants, the largest increases being in sugar beet areas. Autumn migrants were most abundant in East Anglia and Lincolnshire.

It is possible to sample spindle trees during the winter to record the numbers of overwintering eggs. A paper by Way *et al.* (1981) described the use of egg counts and suction trap data to forecast the infestation of field beans by *A. fabae*. They found that:

- Autumn trap catches (the autumn migration back to spindle) were useful as early forecasts of likely very large or very small populations of aphids on field beans (about 8 months later), but that otherwise they lacked precision.
- Egg sampling in winter provided a more accurate forecast approximately 5 months before infestation of the bean crop.
- In May, aphid counts on spindle were most useful for predicting the time of migration and provided approximately 2 weeks warning for insecticide application if needed.
- Captures in the suction traps in spring provided the latest estimate of both the sizes of crop infestations and the best timing for insecticide treatment.
- In terms of forecasting infestation levels, Way *et al.* used criteria as shown in Table 1.1.

Table 1.1. Forecasting criteria for catches in suction traps (from Way *et al.*, 1981). Their 'thresholds' for egg counts on spindle are also shown.

Forecast damage to spring-sown beans	Total aphids/trap (mid September – early November)	Total aphids/trap (May – mid June)	Mean no. eggs/100 buds on spindle
Unlikely	0-15	0-4	0-1
Possible/probable	>15	>4	>1

In a later study by Thacker *et al.* (1997), linear regression models were constructed to describe variation in the abundance of *A. fabae* at one location in Germany. Overwintering egg densities did not appear to be a significant predictor of summer population size. The best predictors of aphid abundance were temperatures in May and rainfall in March and

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also the abundance of winged aphids 2 years previously, which was probably an artifact of the weather pattern at the time. It was hypothesized that much of the variation in *A. fabae* densities in the summer was due to variable rainfall and thus food quality for the aphid at budburst of spindle, the overwintering host.

Objective 2. Summarise Rothamsted suction trap records on captures of Aphis fabae over at least 10 years to indicate the pattern of aphid migration.

Rothamsted Research (Richard Harrington) provided access to suction trap data for *A. fabae*. Data sets were provided for Broom's Barn in Suffolk and Wye in Kent. The data sets cover the period from 1966/67 to 2006 and consist of daily counts of aphids caught in the suction traps. Figure 2.1 shows the typical pattern of aphid migration as shown by suction trap samples (for data from Broom's Barn in 1973). The three phases of migration (Way *et al.*, 1981) are indicated.

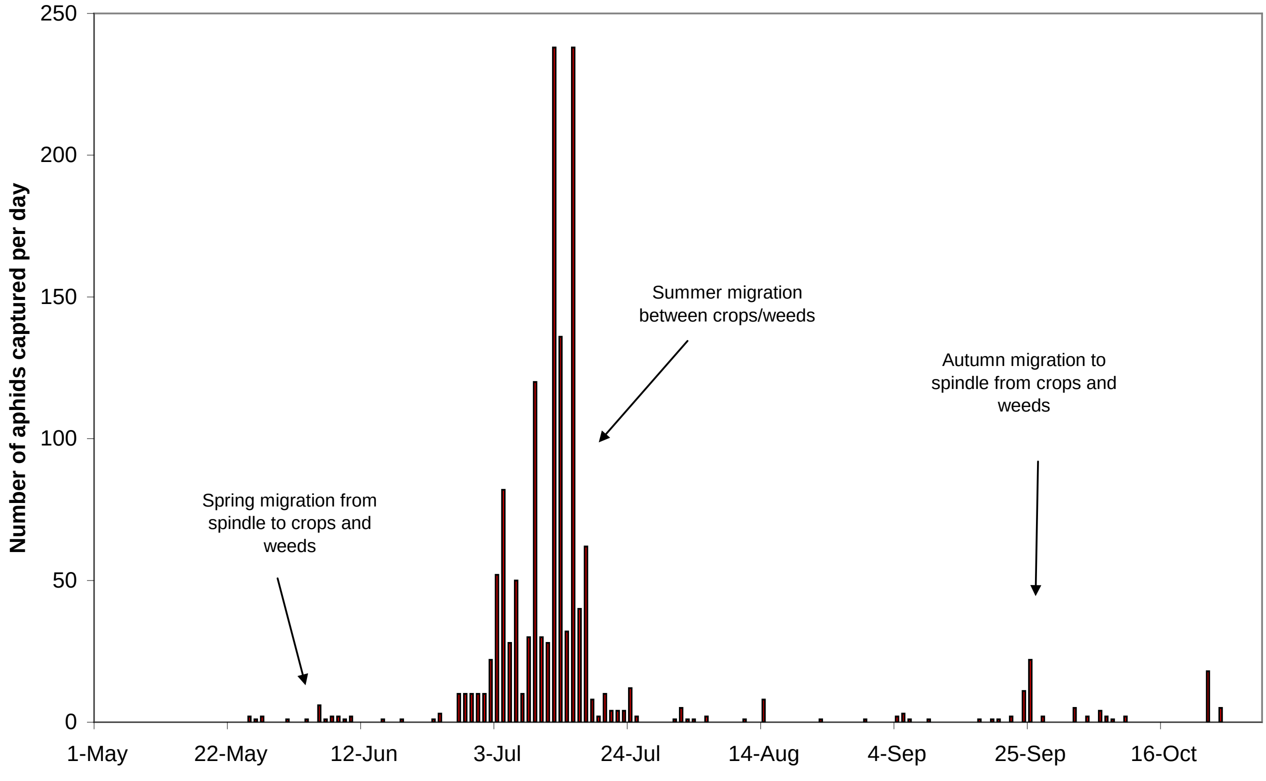

Figure 2.1. Typical pattern of aphid migration as indicated by suction trap samples (for data from Broom's Barn in 1973). The three phases of migration are indicated.

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Aphid abundance

Figures 2.2a and 2.2b show the total numbers of female *A. fabae* caught between 1966/67 and 2006 on each day of the year at the two sites. A small number of male aphids were captured in the autumn as the winged aphids were returning to spindle to overwinter. These data are not shown.

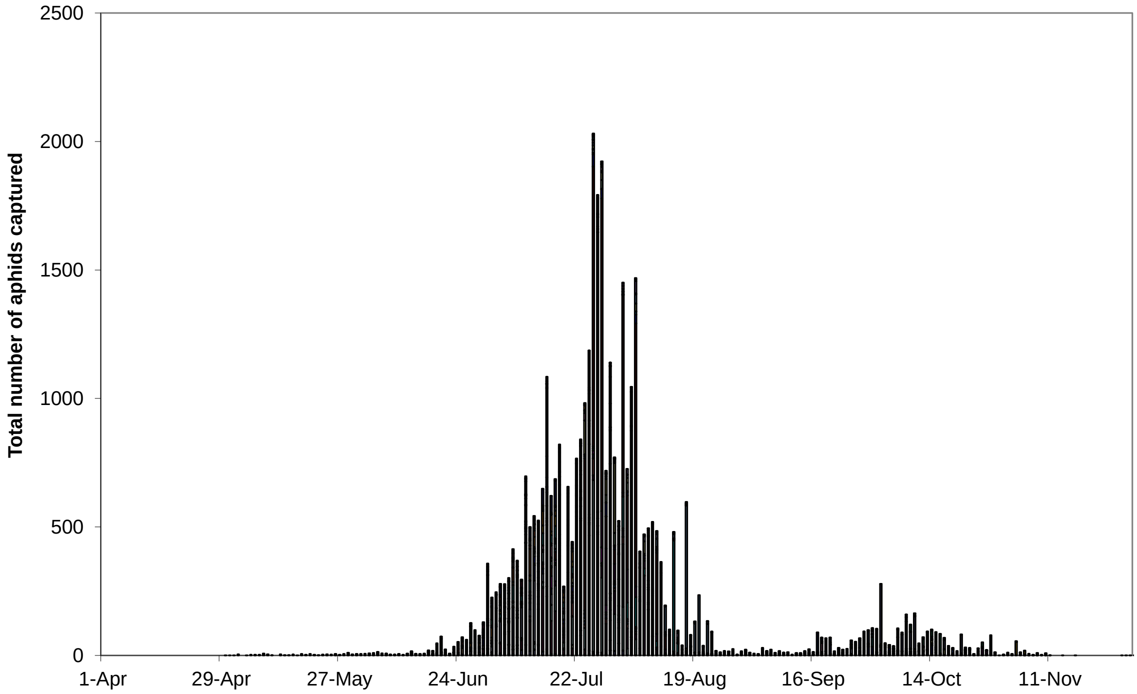

Figure 2.2a. Total numbers of female *A. fabae* caught at Broom's Barn on each day of the year between 1966 and 2006.

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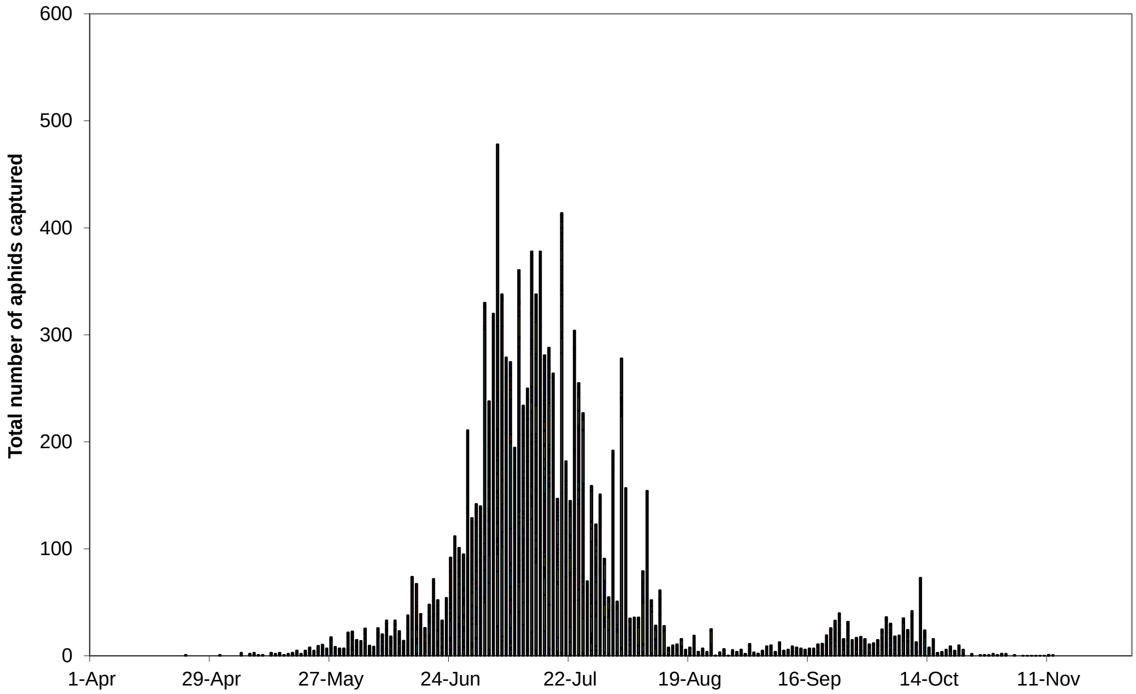

Figure 2.2b. Total numbers of female *A. fabae* caught at Wye on each day of the year between 1967 and 2006.

Table 2.1 shows summary data for the two sites for the numbers of aphids captured up to 31 August each year. The numbers of aphids captured at Broom's Barn were higher on average and more variable from year to year.

Table 2.1 Summary data for the numbers of aphids captured up to 31 August each year.

Site	**Number of years of data**	**Mean number captured**	**Standard error**
Broom's Barn	41	825	232
Wye	40	270	43

Figure 2.3 shows the total number of female aphids captured in the spring (before 15 June) (spring migrants) at both sites. The cut-off date of 15 June was chosen based on the approach used by Way *et al.* (1981) to distinguish spring migrants from summer migrants. Generally, more aphids were caught at Wye than at Broom's Barn. Figure 2.4 shows the total number of aphids caught between 15 June and 31 August (summer migrants) at both sites, aphids were generally more abundant at Broom's Barn during this period. Finally, Figure 2.5 shows the numbers of female aphids captured in the autumn at both sites and again, aphids were generally more abundant at Broom's Barn.

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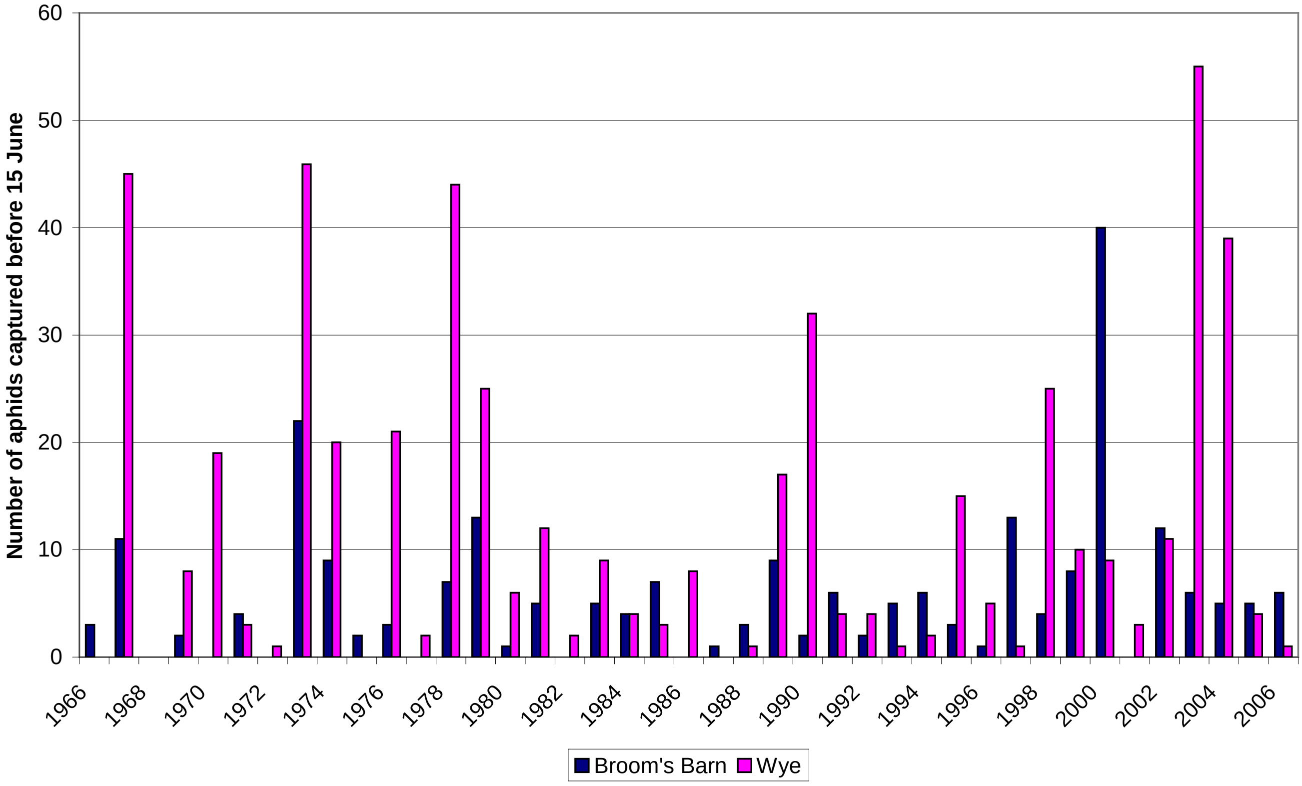

Figure 2.3. The total number of female aphids captured before 15 June at both sites.

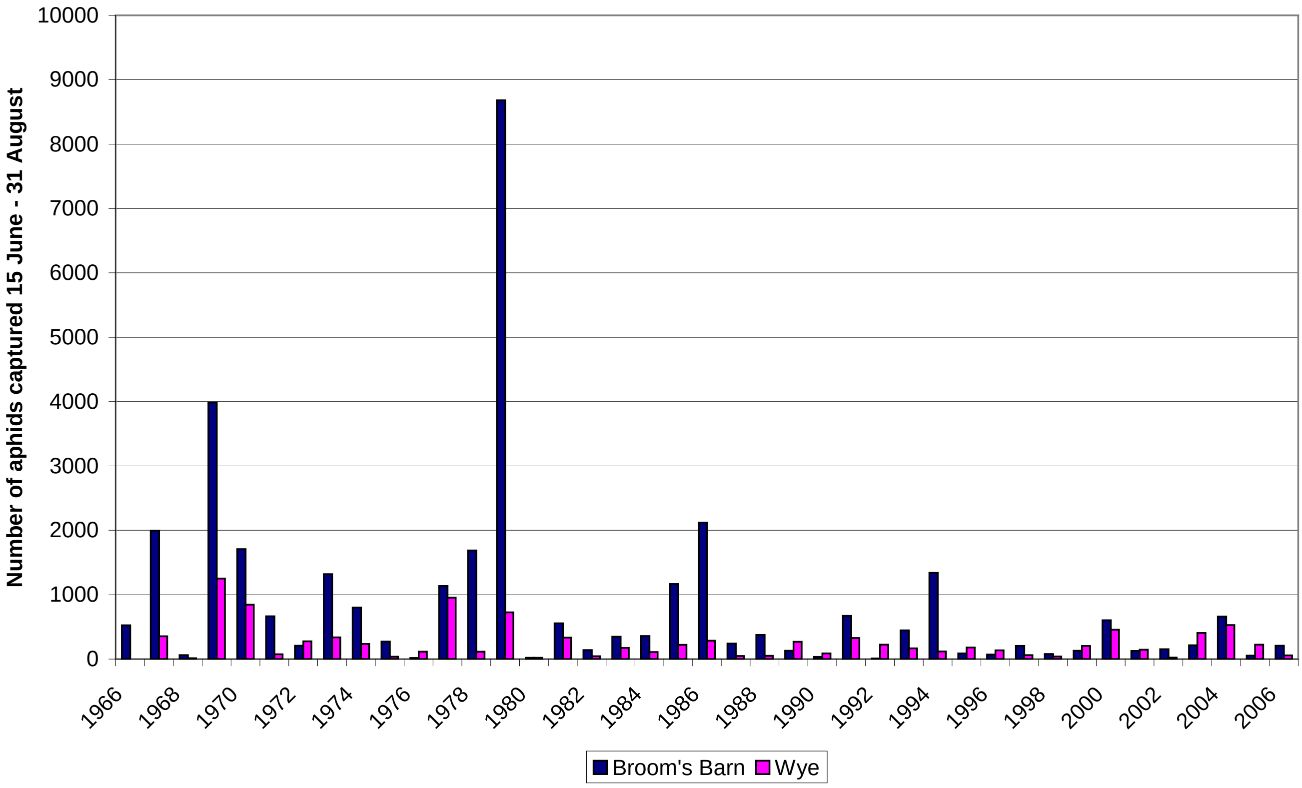

Figure 2.4. The total number of female aphids captured from 15 June – 31 August at both sites.

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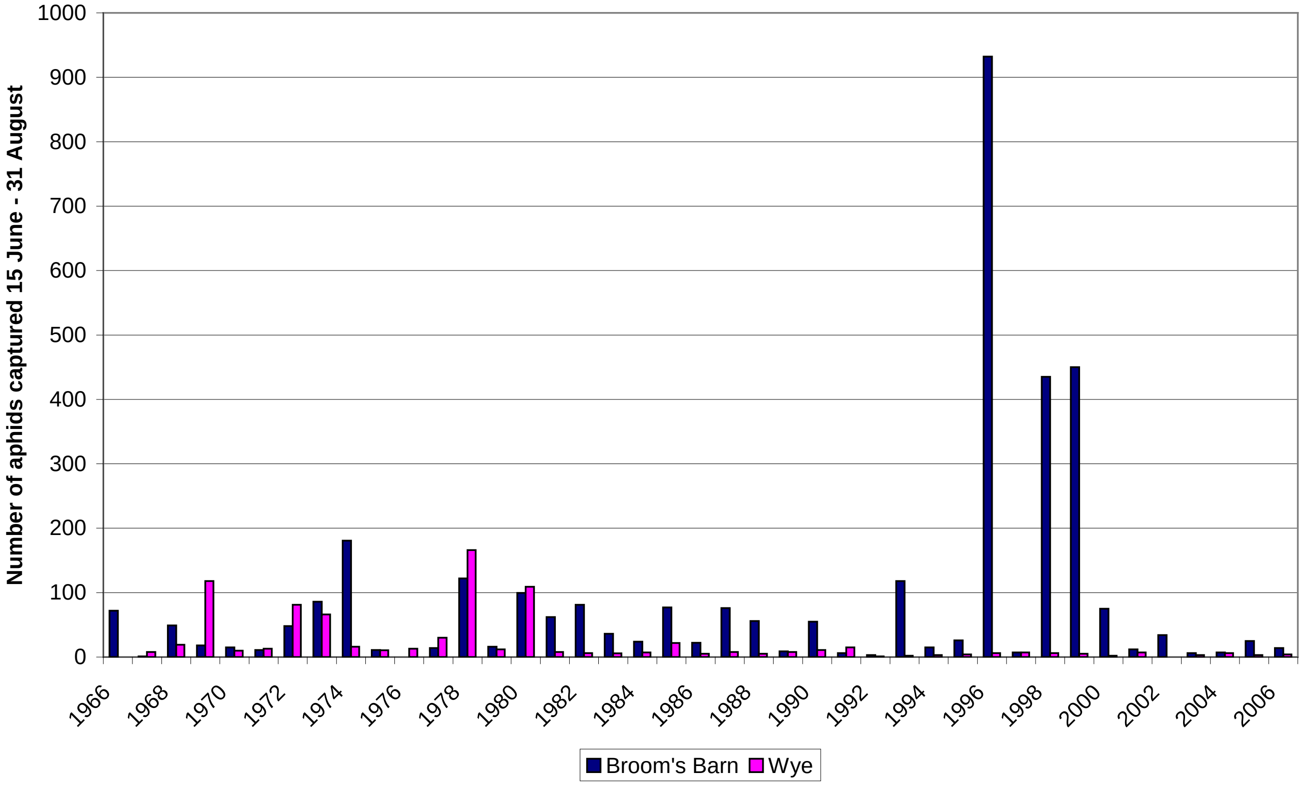

Figure 2.5. The total number of female aphids captured in the autumn at both sites.

Figure 2.6 shows the relationship between spring/summer captures (up to 31 August) at Wye and at Broom's Barn. These are highly correlated ($p<0.001$), indicating a general effect of 'year' on abundance.

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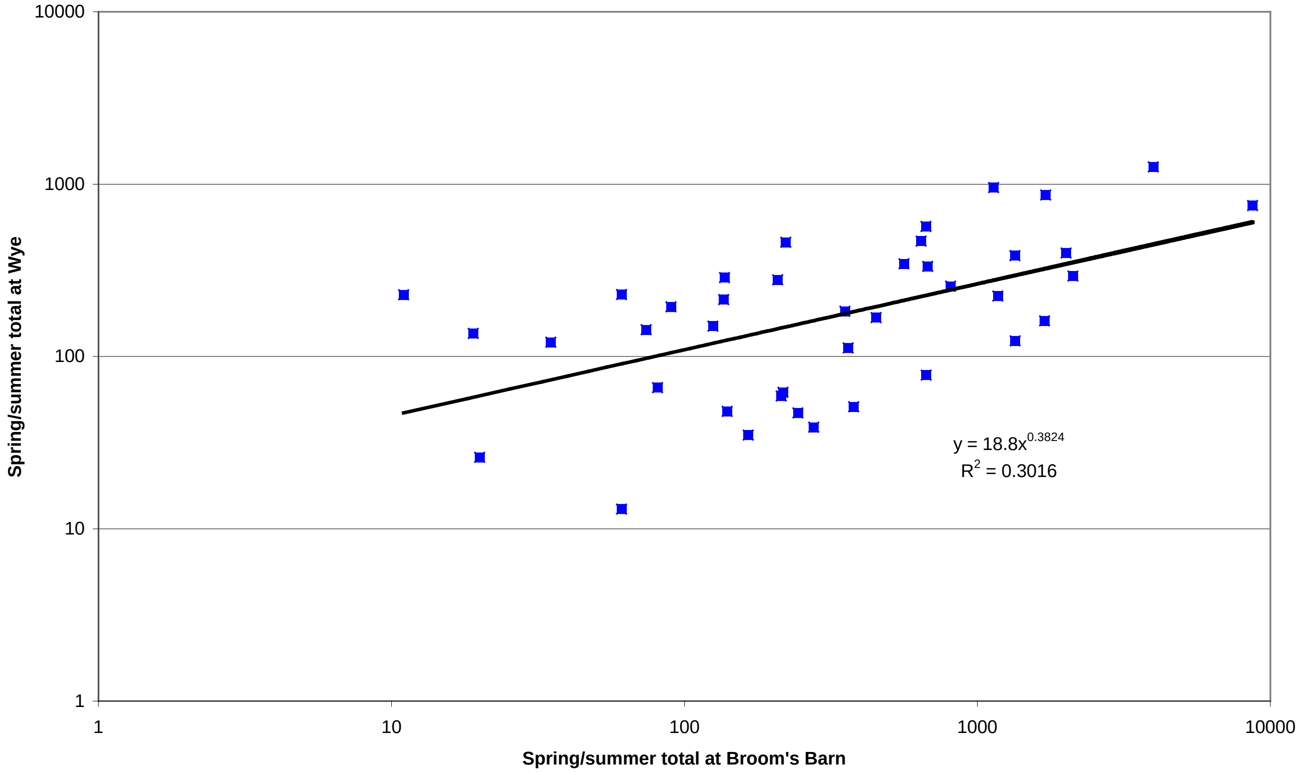

Figure 2.6. Relationship between spring/summer captures at Wye and those at Broom's Barn.

Figure 2.7 shows the relationship between numbers of aphids trapped in spring (up to 15 June) and those trapped in the previous autumn. There was a linear correlation for the data from Broom's Barn ($p<0.01$) but no correlation for the data from Wye.

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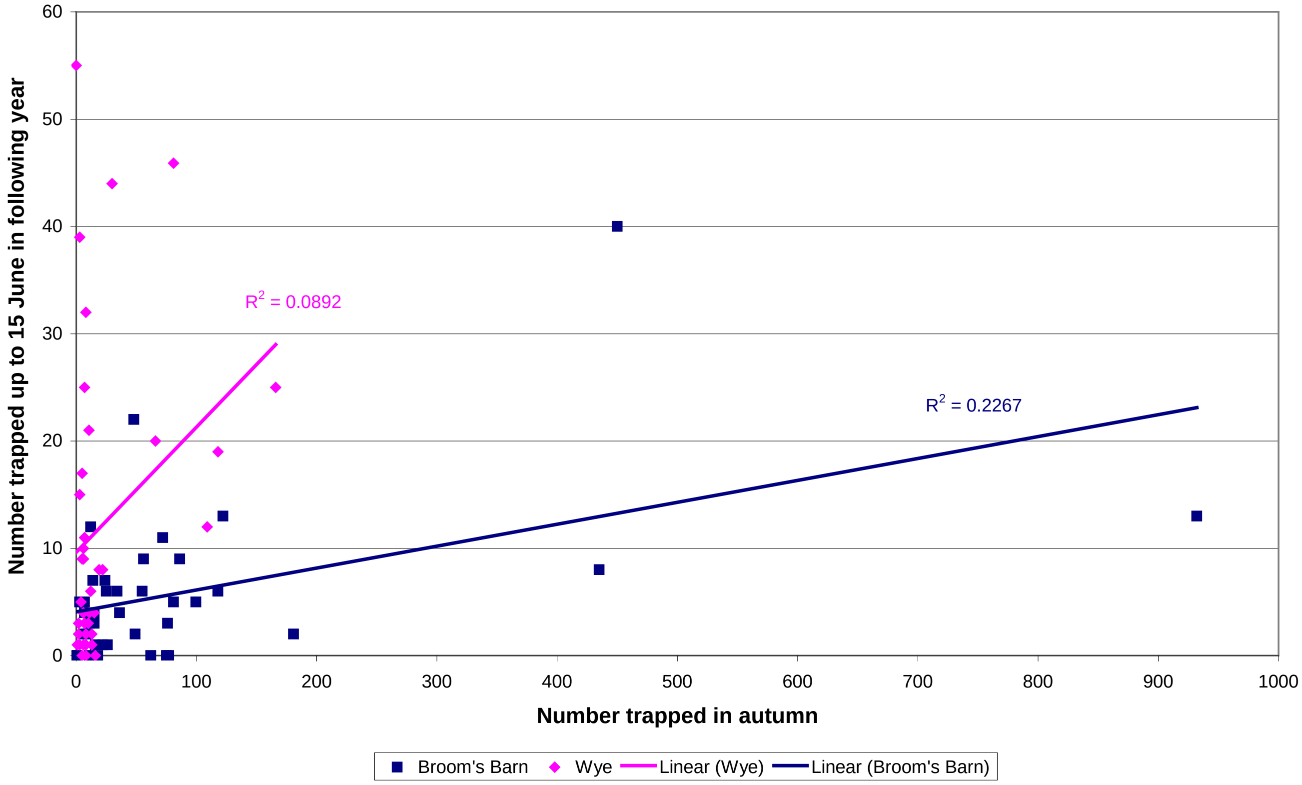

Figure 2.7. Relationship between numbers of aphids trapped in spring (up to 15 June) and those trapped in the previous autumn

Figure 2.8 shows the relationship between numbers of aphids trapped in summer (15 June – 31 August) and those trapped in the previous spring (up to 15 June). There were no correlations.

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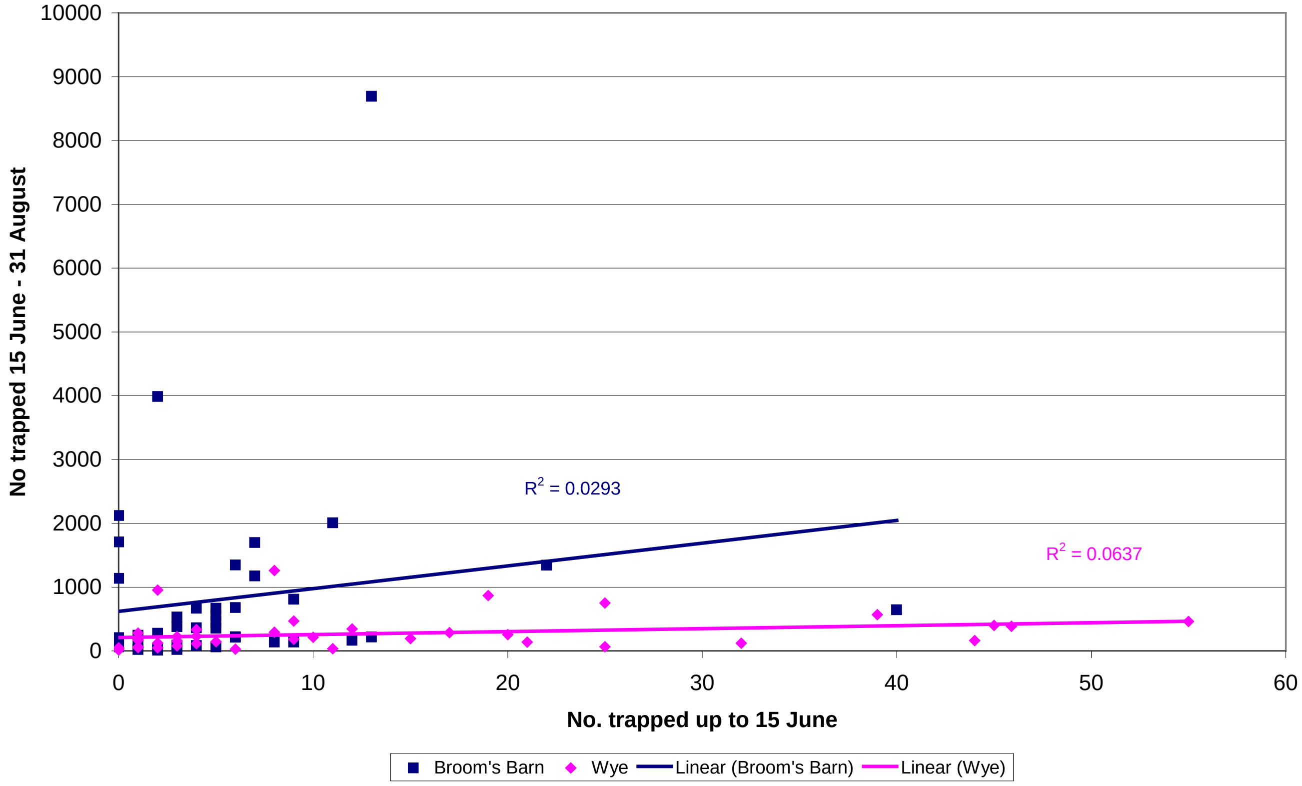

Figure 2.8. Relationship between numbers of aphids trapped in summer (15 June – 31 August) and those trapped in the spring (up to 15 June)

Timing of aphid activity

Figure 2.9 shows the dates when the first aphid was captured each year and the date when 50% of the spring/summer total (up to 31 August) was captured for both Broom's Barn and Wye. The dashed lines show 10-year running means. The running means indicate that both the times of first capture and 50% capture have become earlier during the 40 years of observations. The date of 50% capture is consistently earlier at Wye than at Broom's Barn, but the relationship is less consistent for the date of first capture

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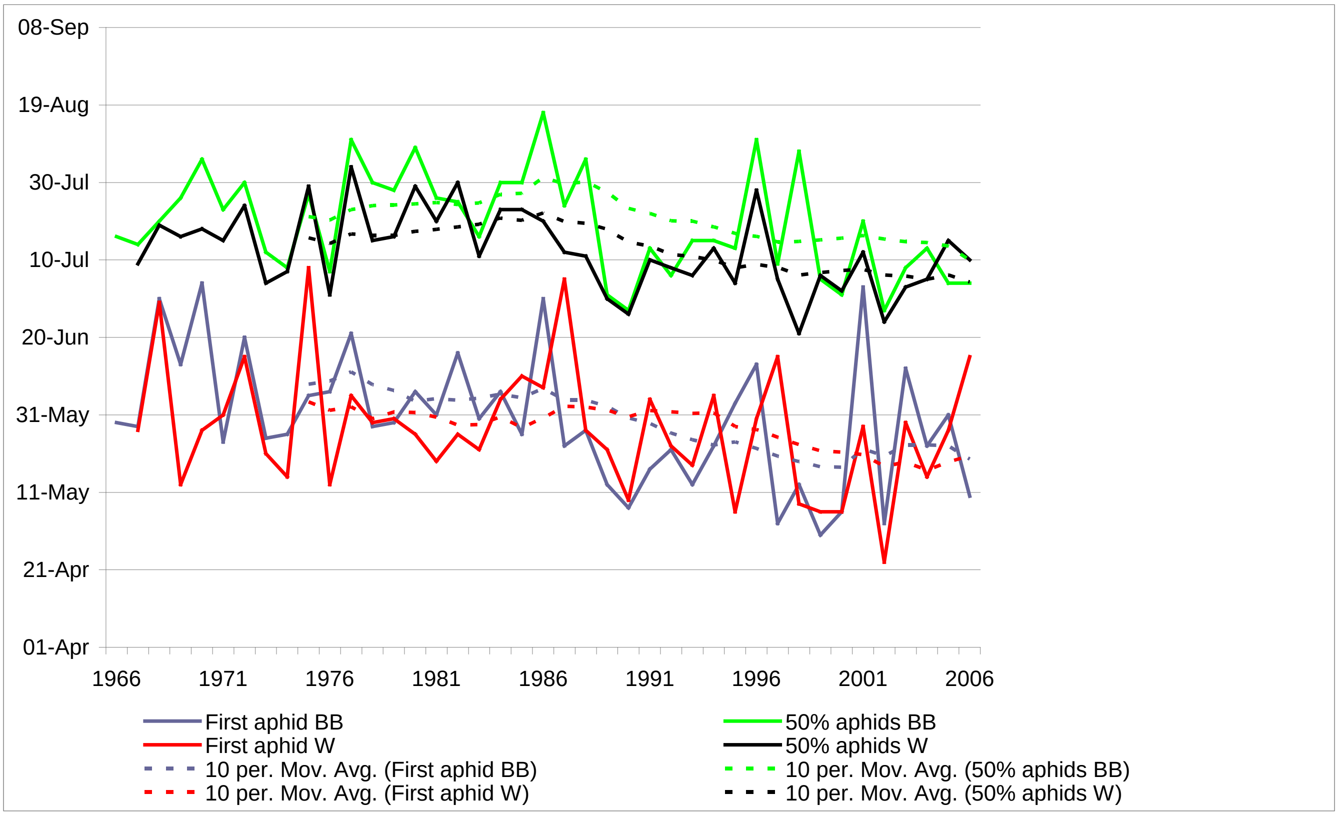

Figure 2.9. The dates when the first aphid was captured each year and the date when 50% of the spring/summer total was captured for both Broom's Barn (BB) and Wye (W). The dashed lines show 10-year running means.

Figure 2.10 shows the relationship between the date the first aphid was captured and the total number of aphids caught between 15 June and 31 August. There were no statistically significant correlations.

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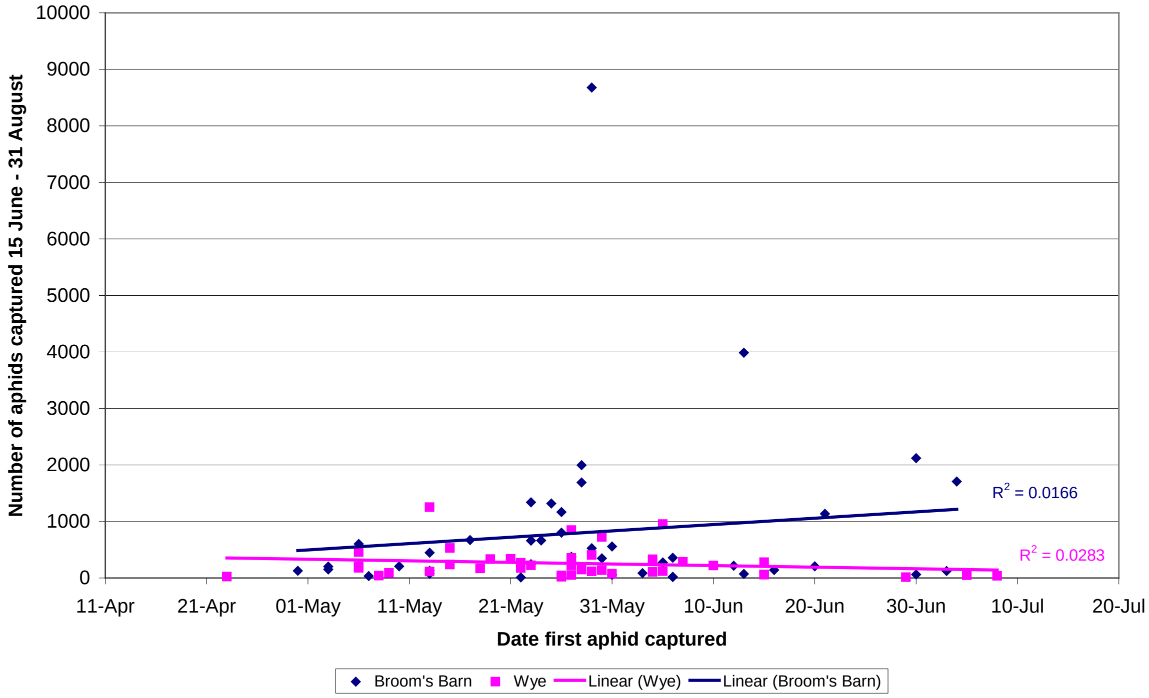

Figure 2.10 The relationship between the date the first aphid was captured and the total number of aphids caught between 15 June and 31 August.

Figure 2.11 shows the relationship between the date 50% aphids were captured and the total number of aphids caught between 15 June and 31 August. There were no statistically significant correlations.

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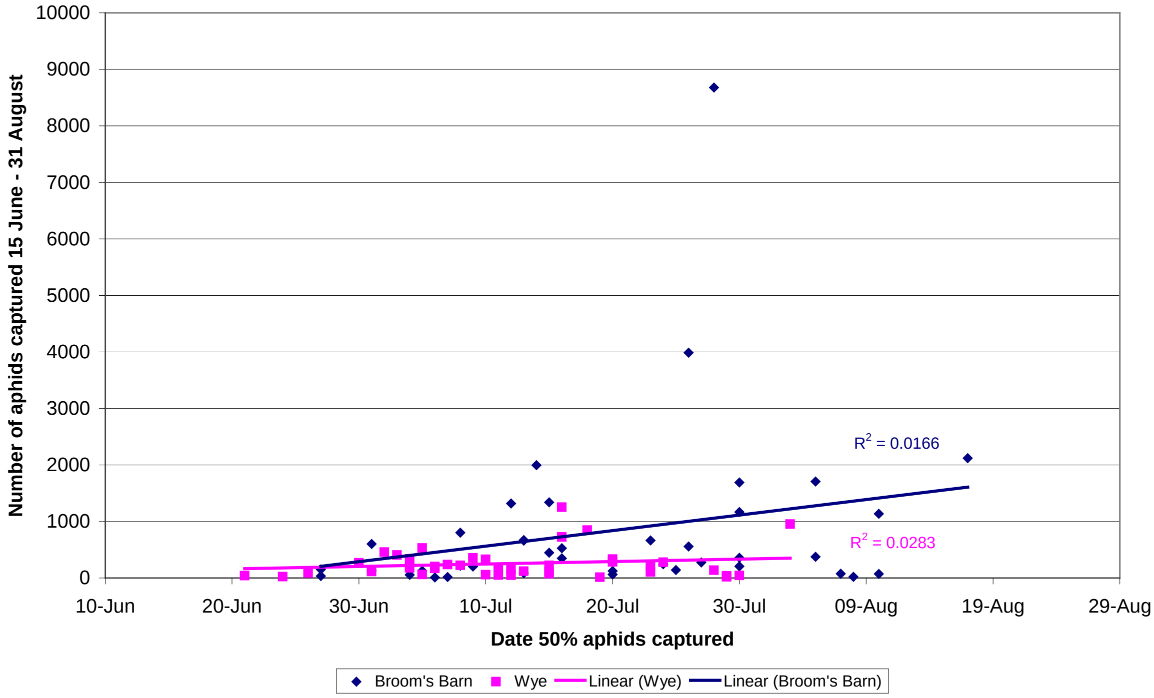

Figure 2.11 The relationship between the date 50% aphids were captured and the total number of aphids caught between 15 June and 31 August.

Objective 3. Look for relationships between aphid flight times/abundance and weather data using information from the literature as available.

The information on key events and abundance from Objective 2 was used to look for relationships between key events, abundance and weather records (temperature and rainfall) for Suffolk and Kent (Lowestoft and Manston respectively). Comparisons on the timing of key events were made with temperature data from January-June. The aphids overwinter as eggs and remain as eggs until at least the end of February. Depending on when they complete diapause development and the low temperature threshold for post-diapause development, they are likely to start responding to 'temperature' some time in January/February. The eggs start hatching in late February and the rates of development of the subsequent stages will be 'driven' by temperature. In terms of 'mortality' and 'reproductive potential' then the egg stage is likely to be relatively unresponsive to weather conditions. Thus comparisons between abundance and temperature or rainfall were made with data from March-June.

Relationships between the timing of aphid activity and temperature

The mean temperature for defined periods in the spring was calculated and was used to determine the relationship between mean temperature and the date of first capture and 50% capture (up to 31 August). Figures 3.1-3.3 show respectively the date of first capture (the

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start of the spring migration) versus the mean temperature for January-April, January-May and January-June inclusive. The date of first capture is highly negatively correlated with all of these measures of mean temperature ($p<0.01$ or $p<0.001$); the warmer the spring, the earlier the first aphid is captured. The relationship for the two sites is also very similar, the fitted lines having similar slopes and intercepts.

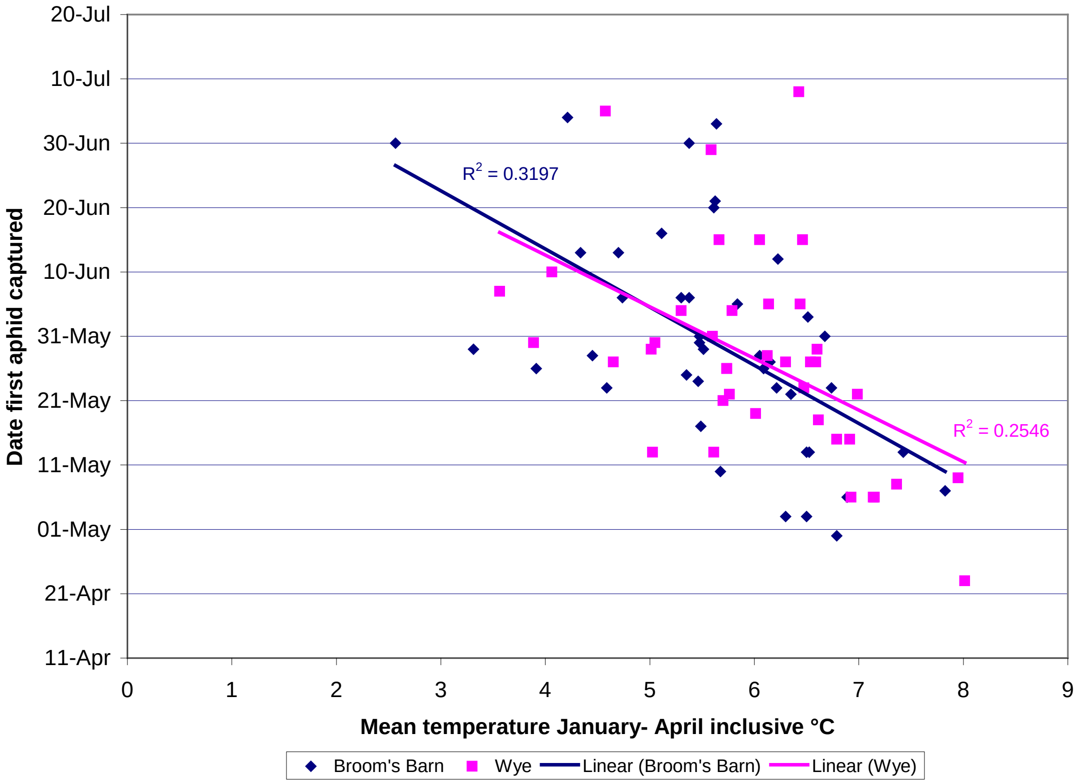

Figure 3.1. Relationship between the date the first aphid was captured and the mean temperature in January-April inclusive.

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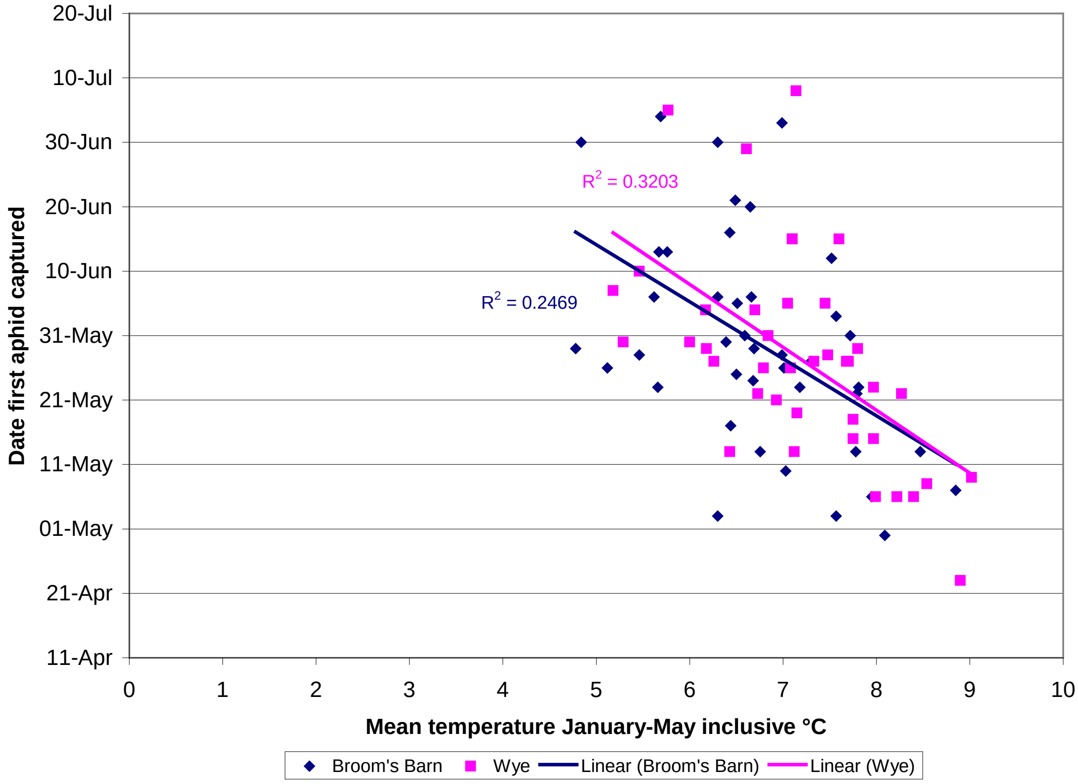

Figure 3.2. Relationship between the date the first aphid was captured and the mean temperature in January-May inclusive.

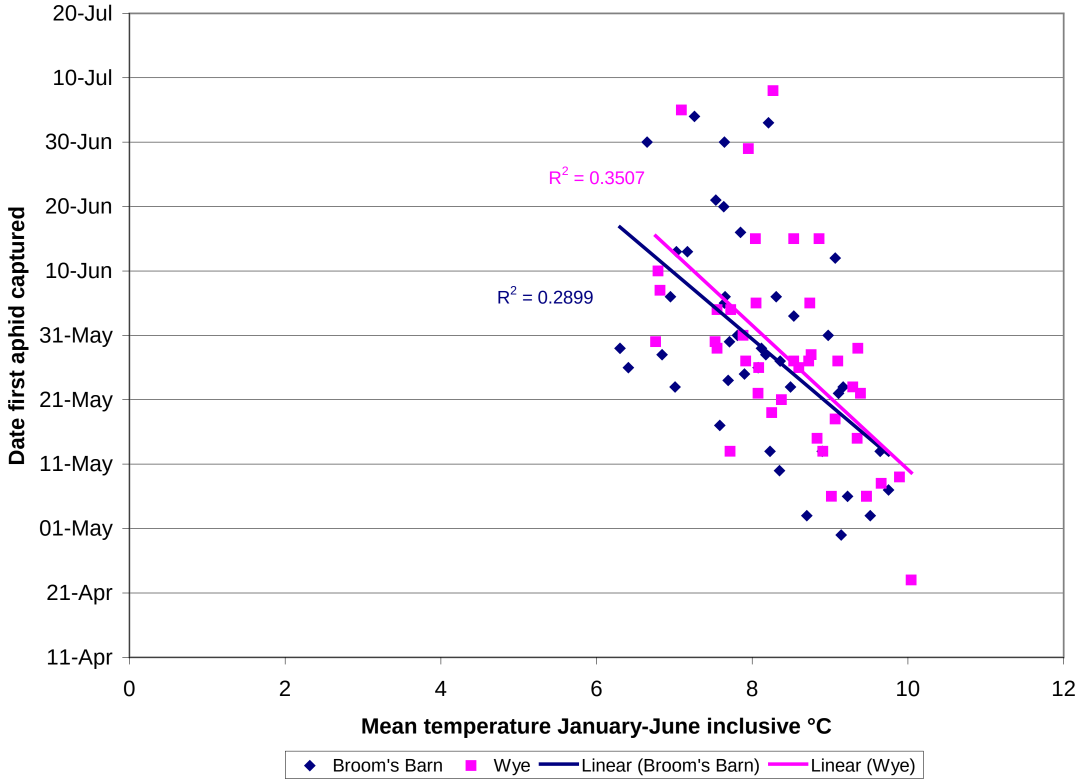

Figure 3.3. Relationship between the date the first aphid was captured and the mean temperature in January-June inclusive.

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Figures 3.4-3.6 show respectively the date of 50% capture (for aphids captured up to 31 August) versus the mean temperature for January-April, January-May and January-June inclusive. The date of 50% capture is highly negatively correlated with all of these measures of mean temperature ($p<0.001$); as with the date of first capture, the warmer the spring, the earlier the date when 50% of aphids were captured. The fitted lines for the two sites are also very similar.

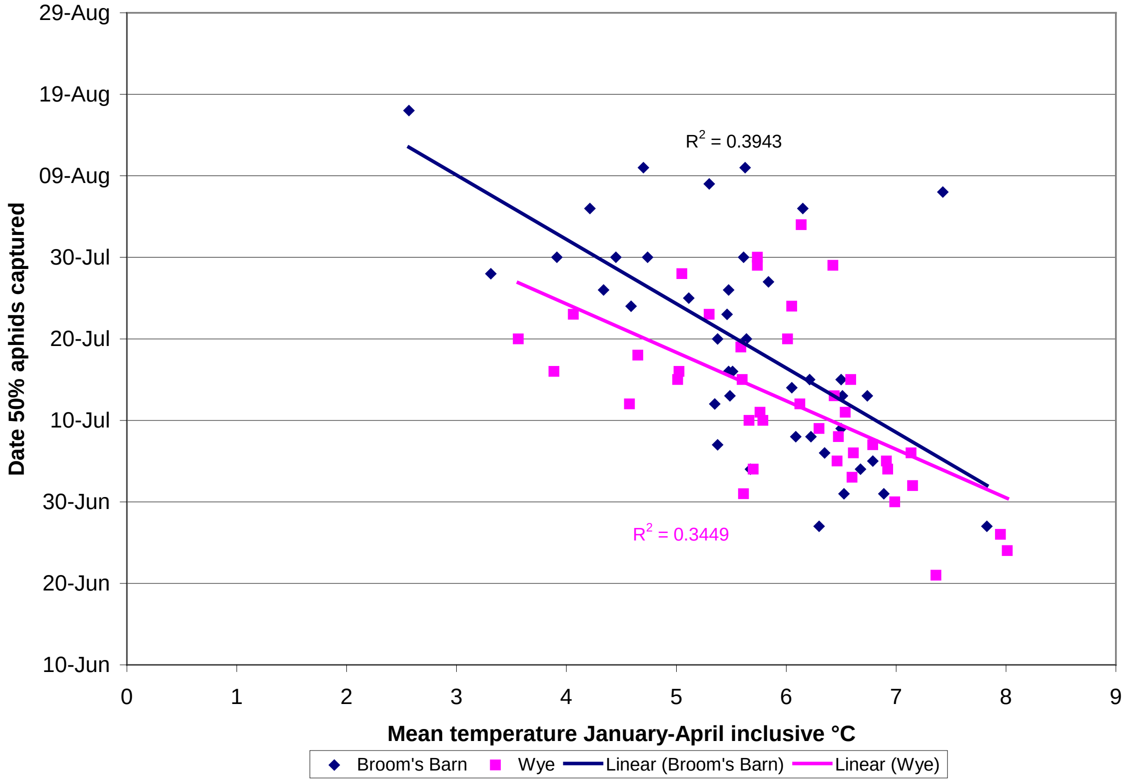

Figure 3.4. Relationship between the date 50% of aphids were captured and the mean temperature in January- April inclusive.

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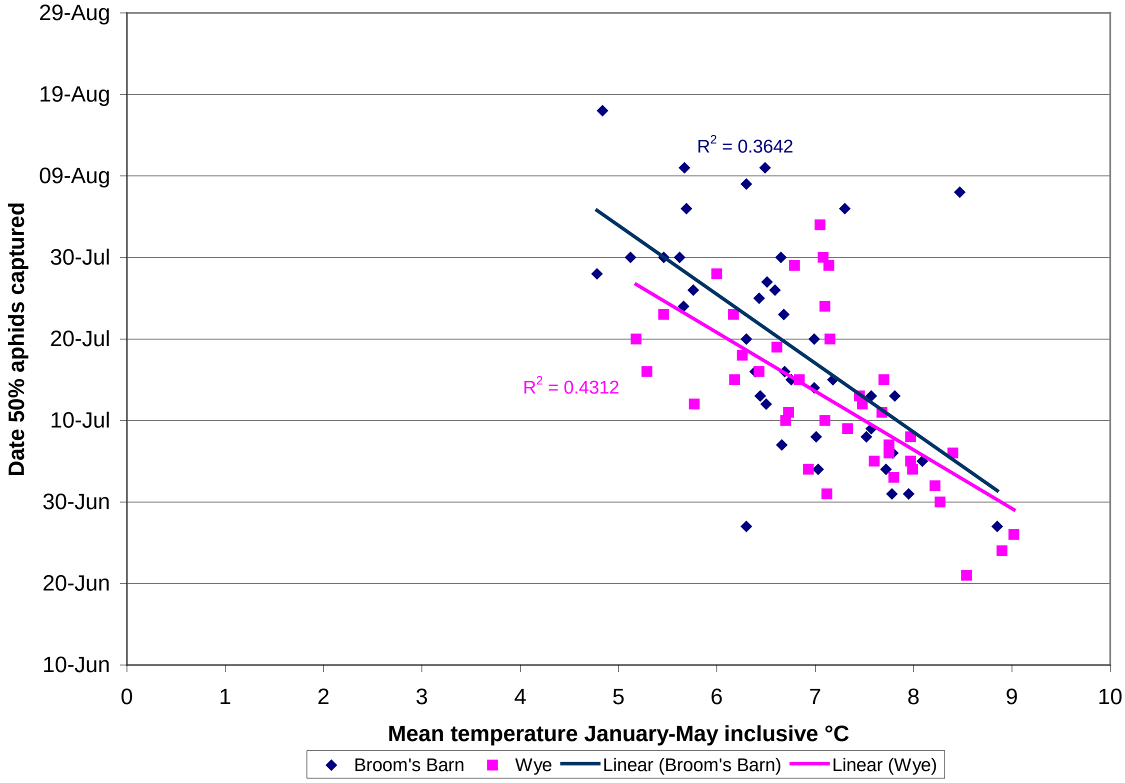

Figure 3.5. Relationship between the date when 50% of aphids were captured and the mean temperature in January-May inclusive.

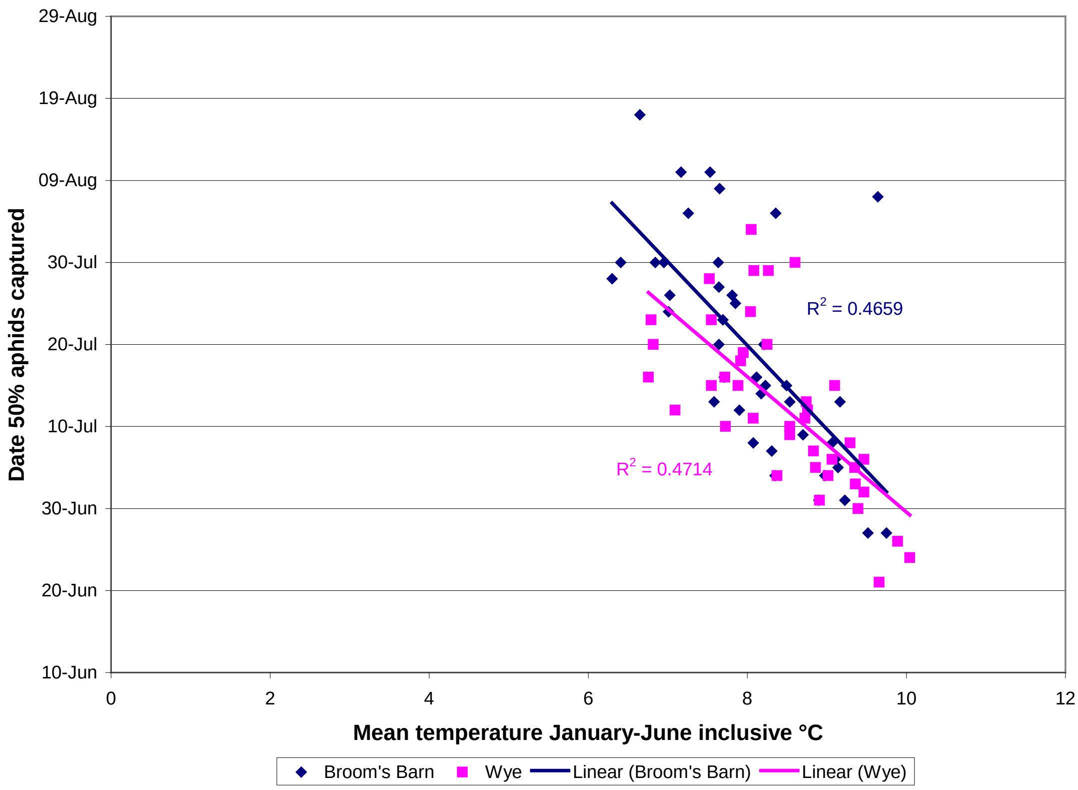

Figure 3.6. Relationship between the date when 50% of aphids were captured and the mean temperature in January-June inclusive.

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Relationships between aphid abundance and rainfall or temperature

Figure 3.7 shows the relationship between the numbers of aphids captured up to 31 August and the mean temperature from January to April inclusive. For Broom's Barn (but not for Wye) the numbers of aphids captured were negatively correlated with the mean temperature ($p<0.001$).

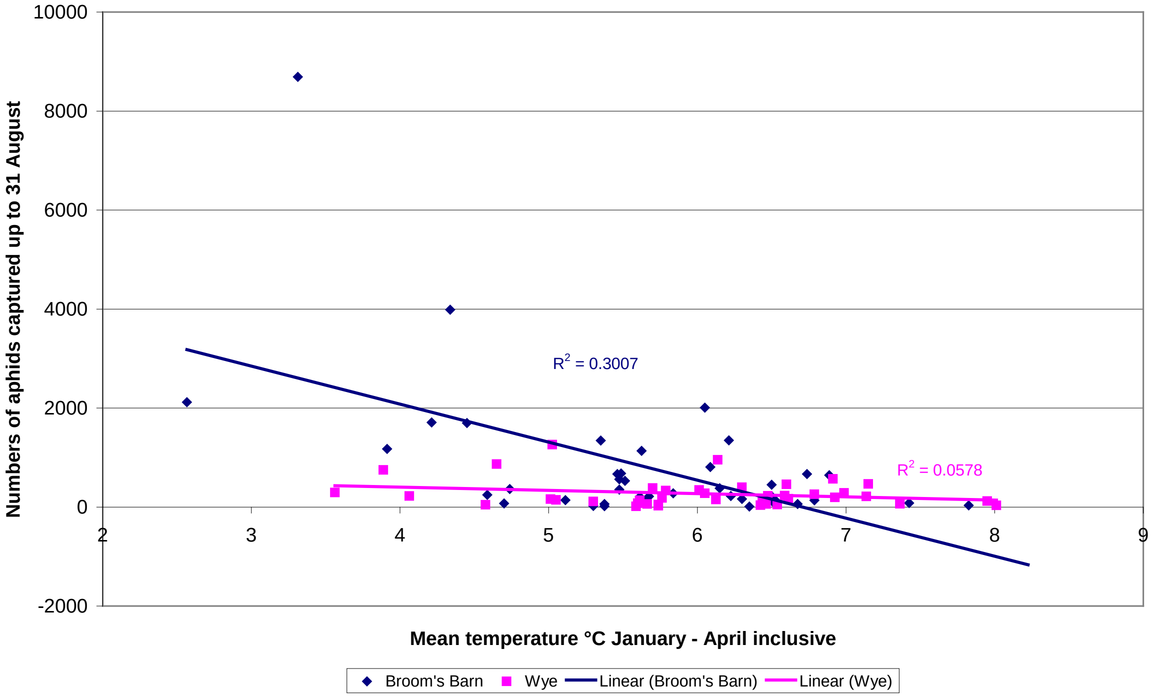

Figure 3.7 The relationship between the numbers of aphids captured up to 31 August and the mean temperature from January to April inclusive.

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Figure 3.8 shows the relationship between the numbers of aphids captured up to 31 August and the mean temperature from January to May inclusive. For Broom's Barn (but not for Wye) the numbers of aphids captured were negatively correlated with the mean temperature (p<0.01).

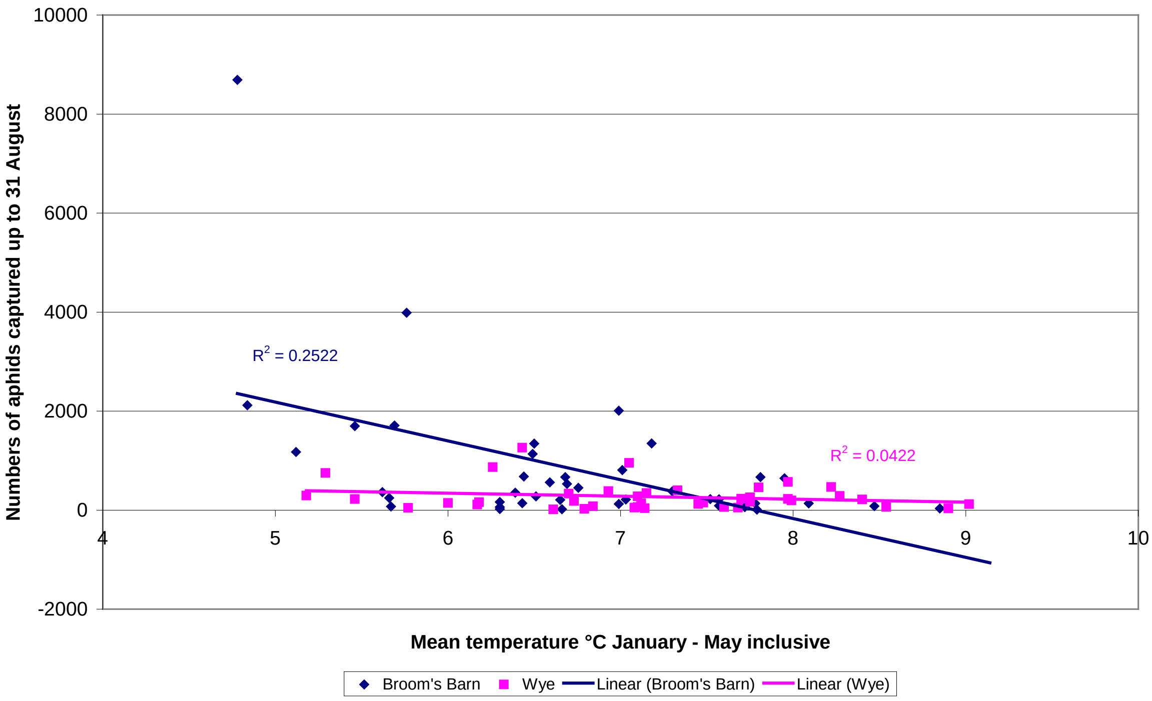

Figure 3.8 The relationship between the numbers of aphids captured up to 31 August and the mean temperature from January to May inclusive.

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Figure 3.9 shows the relationship between the numbers of aphids captured up to 31 August and the mean temperature from January to June inclusive. For Broom's Barn (but not for Wye) the numbers of aphids captured were negatively correlated with the mean temperature ($p<0.01$).

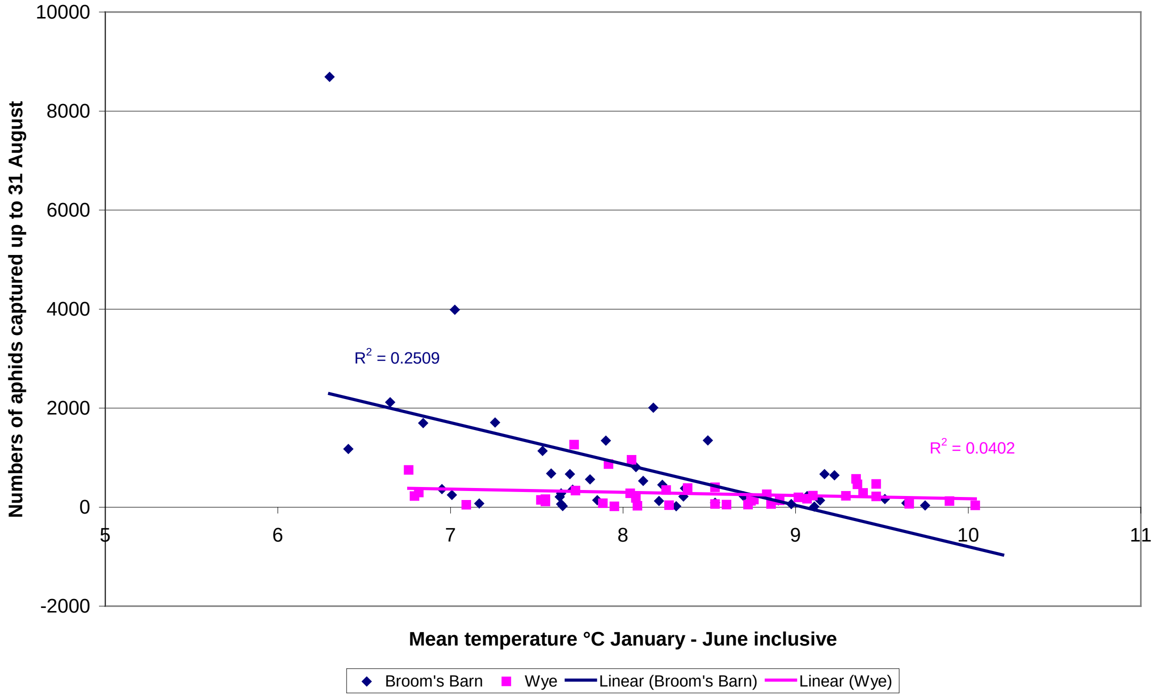

Figure 3.9 The relationship between the numbers of aphids captured up to 31 August and the mean temperature from January to June inclusive.

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Figure 3.10 shows the relationship between the numbers of aphids captured up to 31 August and the mean temperature in March. There were no statistically significant correlations.

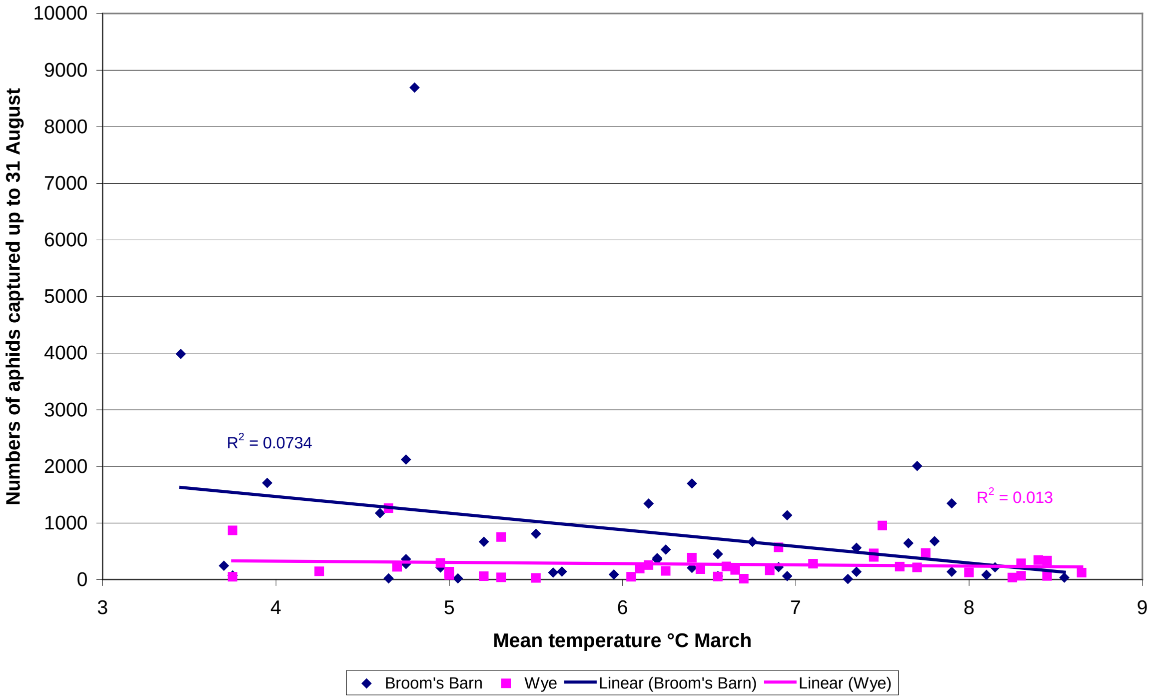

Figure 3.10 The relationship between the numbers of aphids captured up to 31 August and the mean temperature in March.

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Figure 3.11 shows the relationship between the numbers of aphids captured up to 31 August and the mean temperature in April. The numbers of aphids captured at Broom's Barn (but not Wye) were negatively correlated with temperature ($p<0.05$).

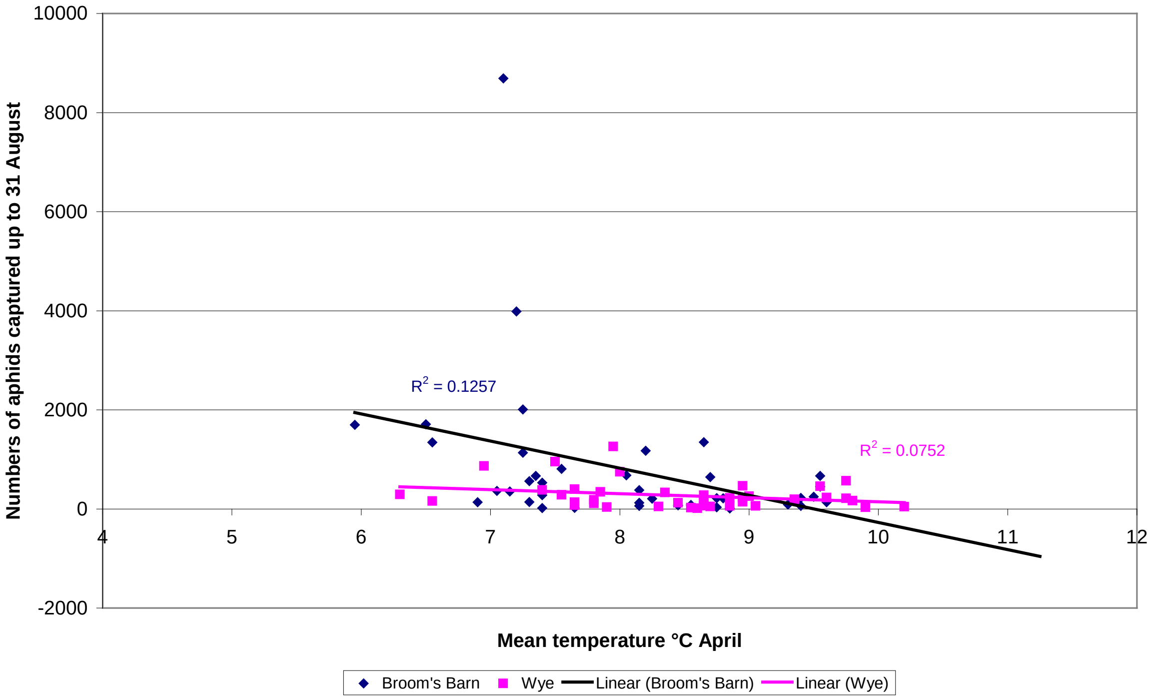

Figure 3.11 The relationship between the numbers of aphids captured up to 31 August and the mean temperature in April.

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Figure 3.12 shows the relationship between the numbers of aphids captured up to 31 August and the mean temperature in May. There were no statistically significant correlations.

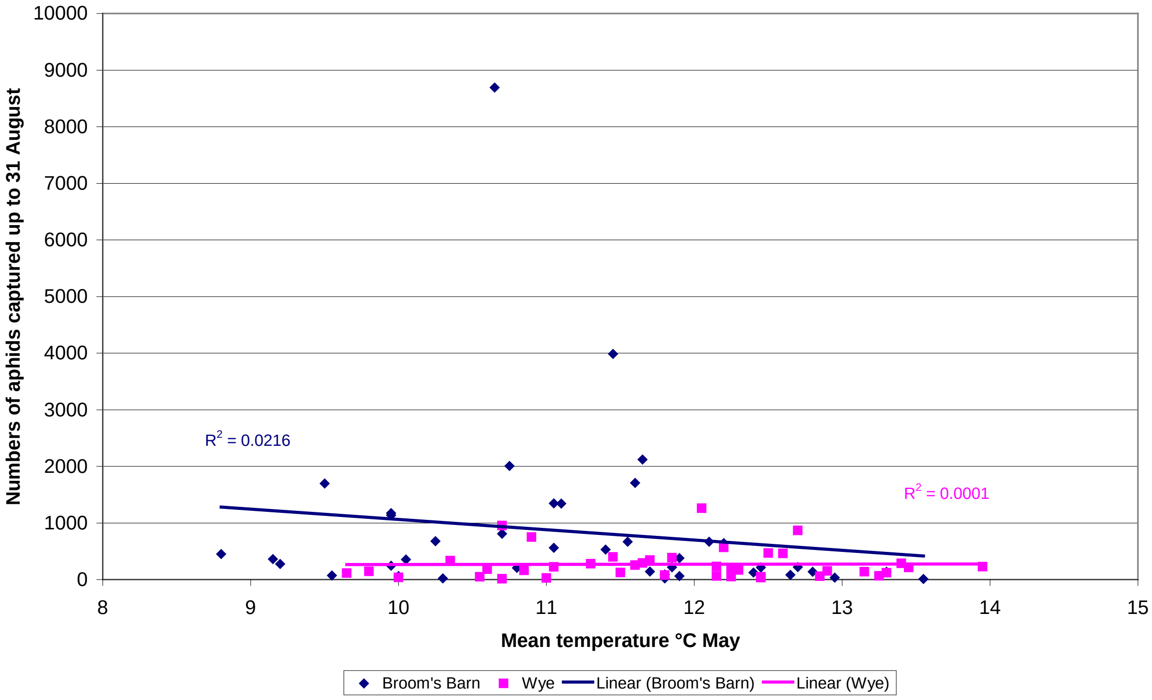

Figure 3.12 The relationship between the numbers of aphids captured up to 31 August and the mean temperature in May.

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Figure 3.13 shows the relationship between the numbers of aphids captured up to 31 August and the mean temperature in June. There were no statistically significant correlations.

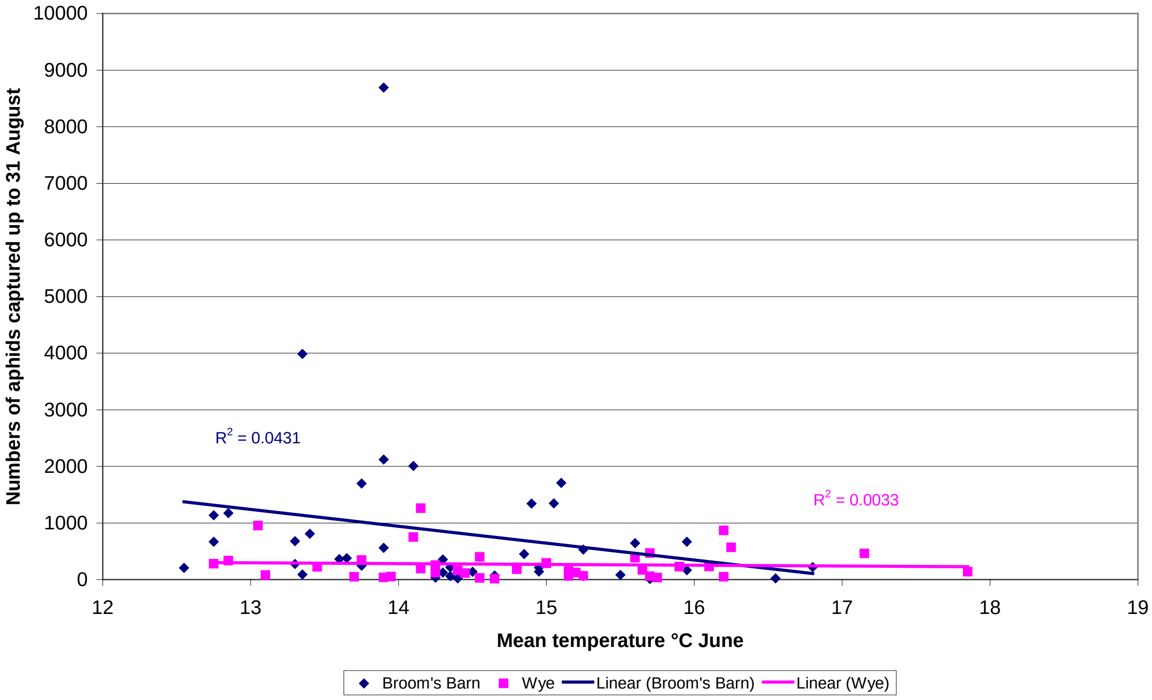

Figure 3.13 The relationship between the numbers of aphids captured up to 31 August and the mean temperature in June.

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Figure 3.14 shows the relationship between the numbers of aphids captured up to 31 August and the rainfall in March. There were no statistically significant correlations.

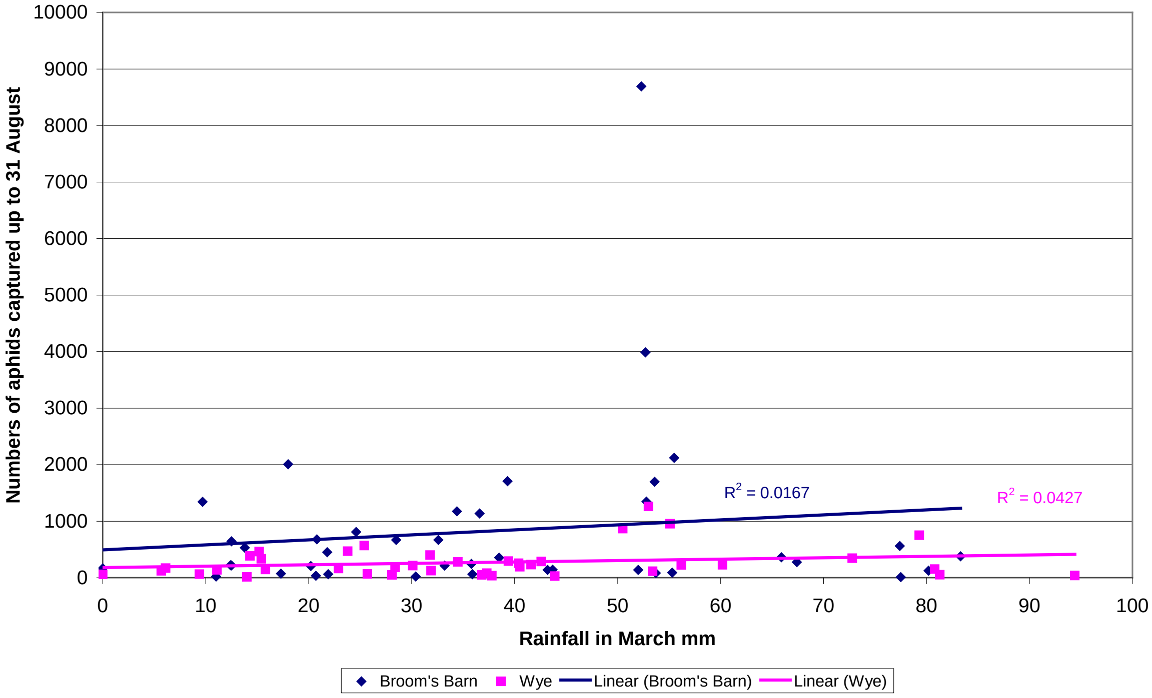

Figure 3.14 The relationship between the numbers of aphids captured up to 31 August and the rainfall in March.

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Figure 3.15 shows the relationship between the numbers of aphids captured up to 31 August and the rainfall in April. There were no statistically significant correlations.

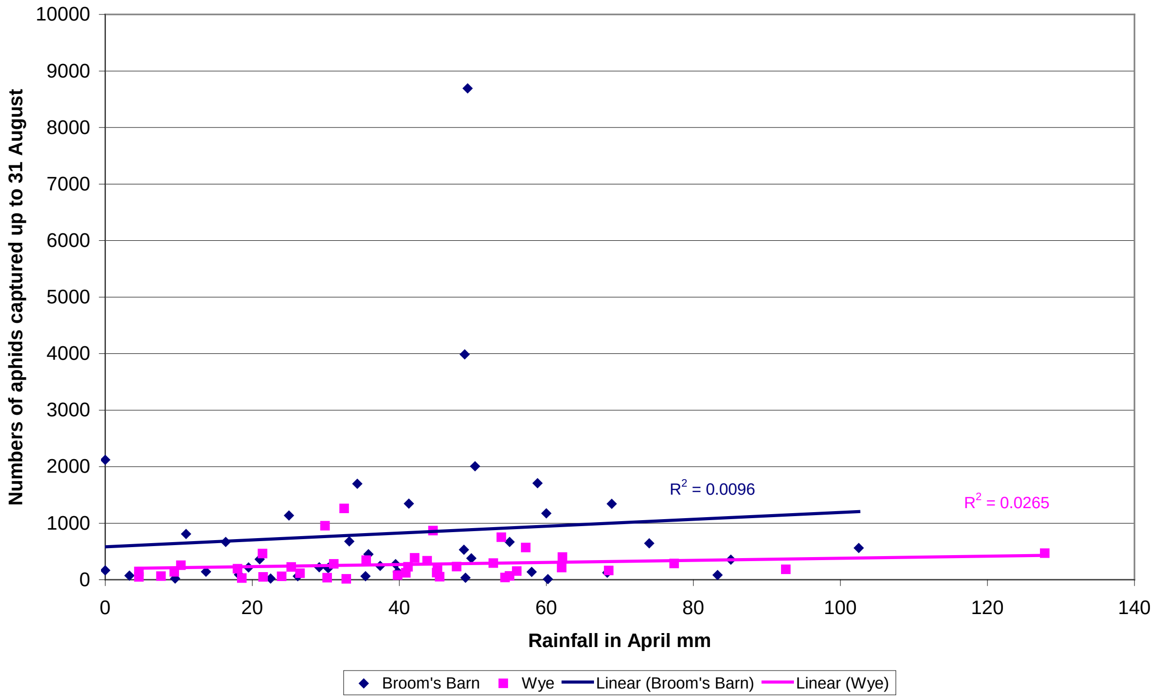

Figure 3.15 The relationship between the numbers of aphids captured up to 31 August and the rainfall in April.

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Figure 3.16 shows the relationship between the numbers of aphids captured up to 31 August and the rainfall in May. For Broom's Barn only, the numbers of aphids captured were positively correlated with rainfall in May ($p<0.05$).

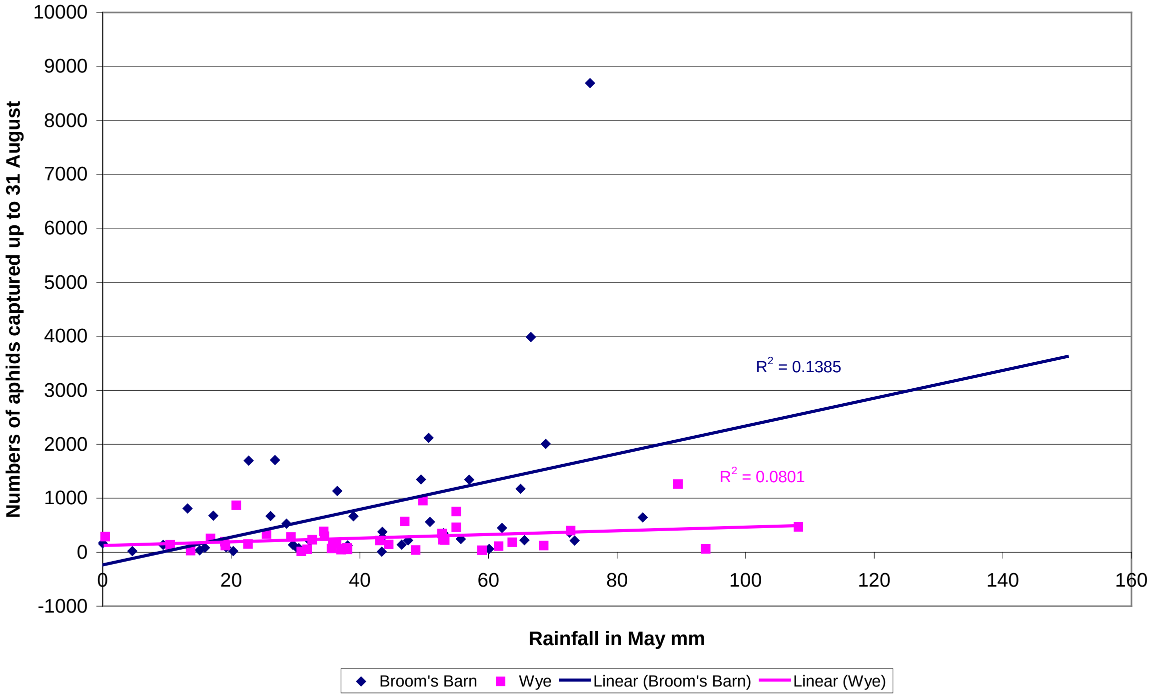

Figure 3.16 The relationship between the numbers of aphids captured up to 31 August and the rainfall in May.

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Figure 3.17 shows the relationship between the numbers of aphids captured up to 31 August and the rainfall in June. There were no statistically significant correlations.

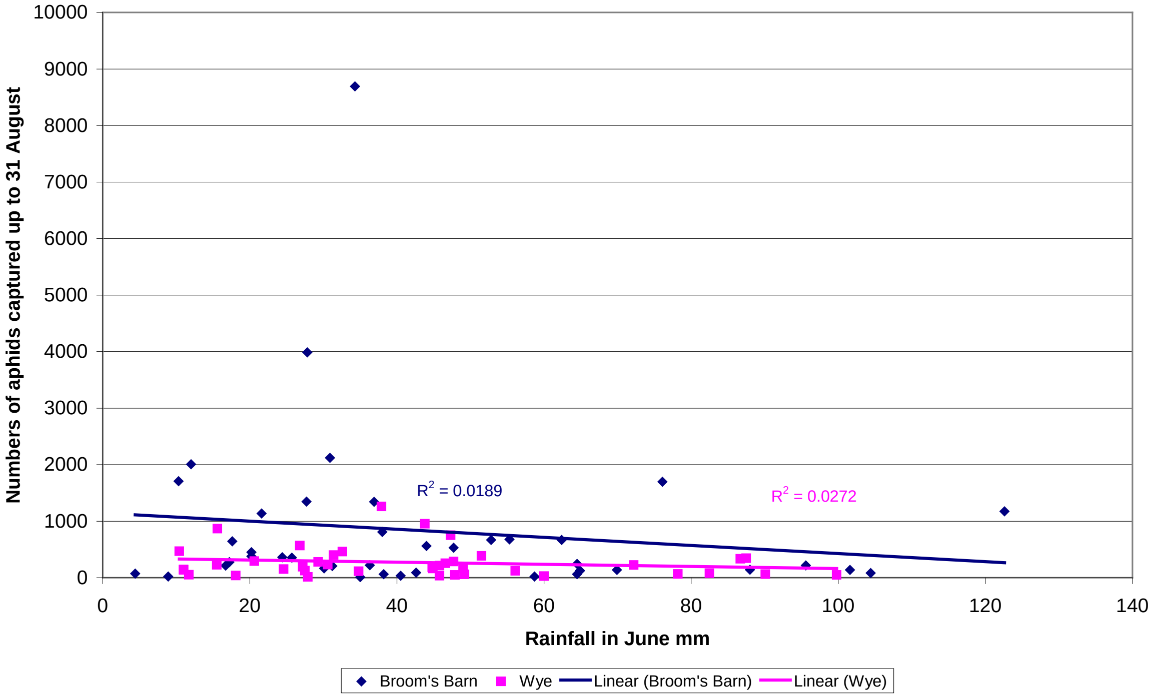

Figure 3.17 The relationship between the numbers of aphids captured up to 31 August and the rainfall in June.

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Figure 3.18 shows the relationship between the numbers of aphids captured up to 31 August and the rainfall in July. There were no statistically significant correlations.

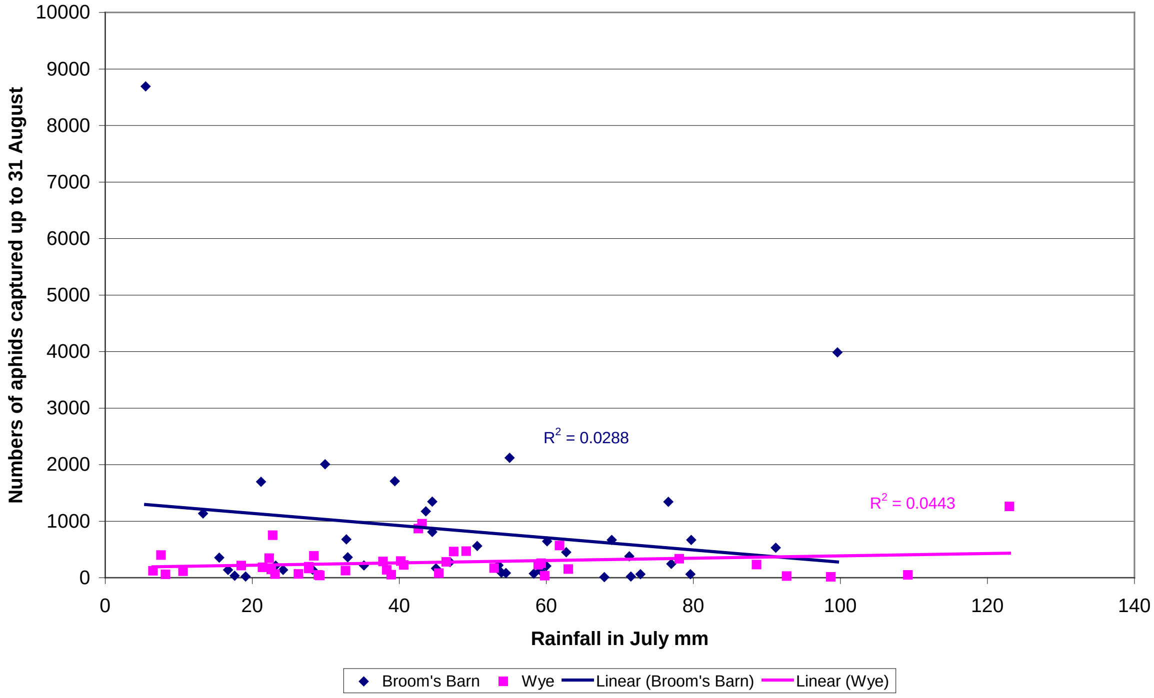

Figure 3.18 The relationship between the numbers of aphids captured up to 31 August and the rainfall in July.

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Figure 3.19 shows the relationship between the numbers of aphids captured up to 31 August and the rainfall in March-June. There were no statistically significant correlations.

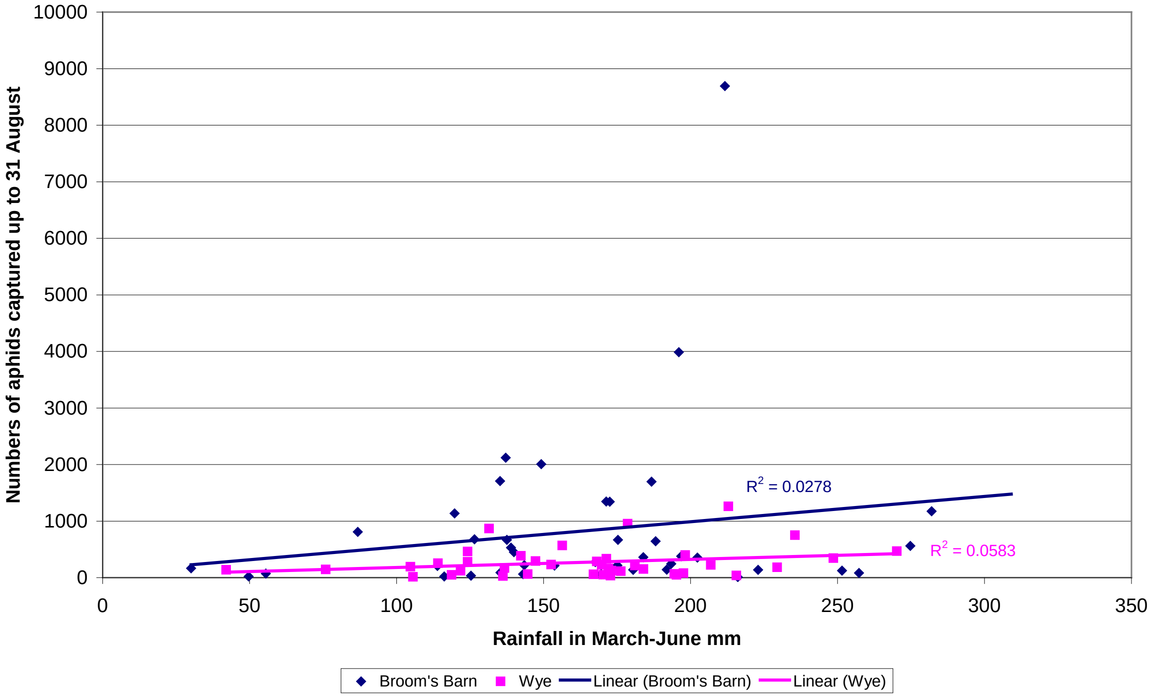

Figure 3.19 The relationship between the numbers of aphids captured up to 31 August and the rainfall in March-June.

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Figure 3.20 shows the relationship between the numbers of aphids captured up to 31 August and the rainfall in April-June. There were no statistically significant correlations.

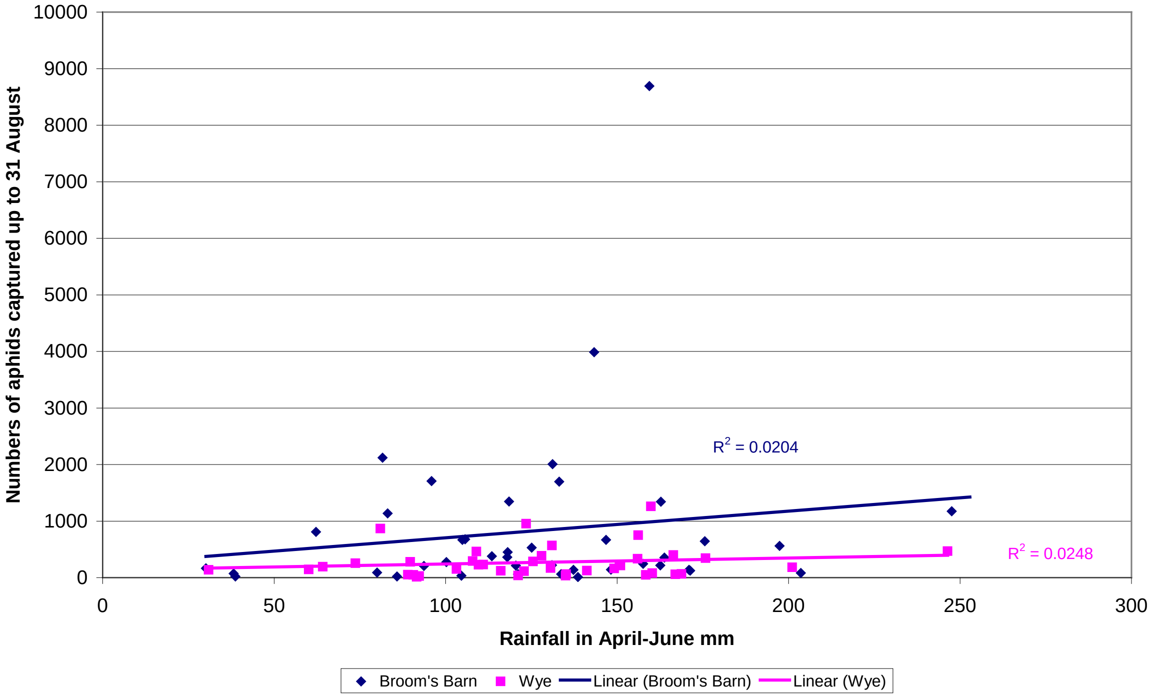

Figure 3.20 The relationship between the numbers of aphids captured up to 31 August and the rainfall in April-June.

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Figure 3.21 shows the relationship between the numbers of aphids captured up to 31 August and the rainfall in May-June. There were no statistically significant correlations.

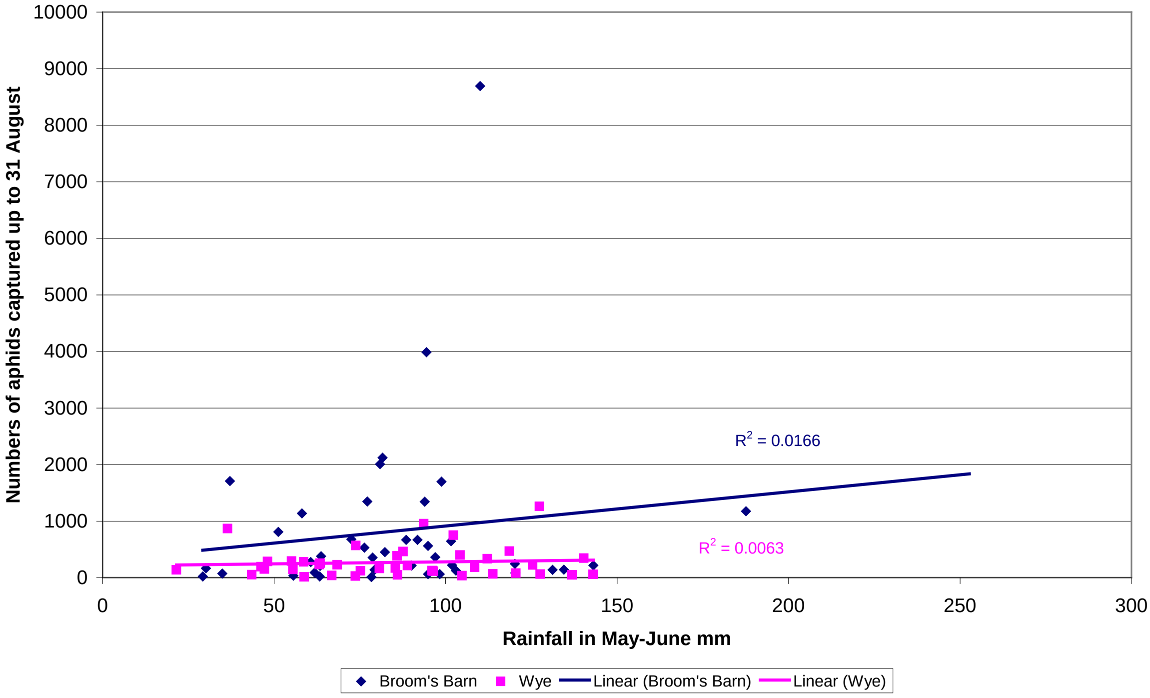

Figure 3.21 The relationship between the numbers of aphids captured up to 31 August and the rainfall in May-June.

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Discussion

This analysis was obviously limited, firstly because only data from two suction trap sites were used and secondly because the weather data sets were not from sites that were particularly close to the suction traps, nor were daily records available. Thus the data can be used only to indicate trends that can be used to suggest a way forward (Objective 4).

Key points are:

1. The numbers of aphids captured in the suction traps and the precise timing of their three periods of migration vary from year to year at any site.
2. There appears to be an overall effect of 'year' on aphid abundance (but only two sites were compared).
3. Overall, the timing of the spring and summer migration has become earlier over the last 40 years.
4. In the spring migration, aphids were generally more abundant at Wye (although this may be an artifact of using a fixed date to separate spring and summer migrants). The situation was reversed during the summer and autumn migrations.
5. At Broom's Barn, the numbers of aphids trapped in the spring were correlated with those trapped in the previous autumn; this was not the case for Wye.
6. At both sites, the date of capture of the first aphid each year was negatively correlated with a measure of accumulated temperature (mean temperature over different periods).
7. The same was true for the date of 50% capture (aphids up to 31 August).
8. There was no clear relationship between abundance and either rainfall or temperature using the restricted weather data sets available. However, there did appear to be a negative relationship between aphid abundance and temperature (January-April, January-May, January-June and April) for Broom's Barn, but not for Wye. In addition, for Broom's Barn only there was a positive relationship with May rainfall.

This superficial analysis shows that aphid abundance is very variable from year to year and more so at Broom's Barn than at Wye. However, although it varied between the two sites, there does appear to be an effect of 'year' on aphid abundance. The effect of 'year' may be the result of abiotic and/or biotic factors, so potentially the effects of weather either directly or indirectly (i.e. through effects on host plants and the effects of natural enemies

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(predators, parasitoids, pathogens)). *Aphis fabae* populations are subject to mortality as a result of predation by natural enemies on both their winter and summer hosts (Way & Banks, 1964; 1967; 1968, Banks, 1968). However, it is not possible at present to predict on an annual basis the impact of natural enemies on field populations of any species of pest aphid. Populations are also affected by ants which can effectively protect the aphids from predators for a period of time (Banks & Macaulay, 1967).

The analysis has not detected any obvious strong relationships with either temperature or rainfall, although previous studies by Way (1967) and Thacker *et al.* (1997) indicated that such relationships might occur. This may be because the temperature and rainfall parameters used in this project are too crude (because no daily records were available or because the sites where weather data were recorded were too remote from the suction trap sites (distances of 25 and 60 miles for the suction traps at Wye and Broom's Barn respectively) or because the statistically significant relationships in the other studies occurred by 'chance', being based on smaller sets of data where the specific weather patterns favoured particular correlations (e.g. both Way and Thacker *et al.*, observed cycling between years in population size and this is not obvious from the larger data sets used in this study).

The analysis also shows that the relative abundance of aphids at the two trap sites varies during the season, with aphids being more abundant at Wye in the spring and less abundant in the summer and autumn. This may reflect the relative abundance of winter and summer host plants in these areas with the winter host, spindle, possibly being more abundant near Wye and the summer hosts (sugar beet and beans) being more abundant near Broom's Barn, as suggested by Cammell *et al.*, (1989). However, it may also be an artifact of the method (a fixed date) used to separate the spring and summer migrations. Again, when the numbers captured up to 31 August were considered, they were lower and less variable at Wye than at Broom's Barn and this may again reflect the relative abundance of host plants in these two areas at different times of the year.

The timing of aphid migration also varies from year to year and site to site, but in this case there is a very strong correlation with the mean temperature over different periods leading up to the spring and summer migrations. The high correlation coefficients and the similarity of the fitted lines for the two sites (slope and intercept) indicate that this is a robust relationship with temperature and that the timing of key events should be highly predictable using accumulated temperatures (day-degrees). Such day-degree forecasts have been used successfully for other pest aphids that overwinter as eggs on woody hosts (e.g. willow-

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carrot aphid, lettuce root aphid – used on the HDC Pest Bulletin).

As stated above, it is not clear why the numbers of aphids captured in suction traps decline between the peak in July/August and the autumn migration (numbers may still be increasing on plants) but it may be another example of the 'aphid crash' (Karley *et al.*, 2004). This project has found strong relationships between the timing of the spring and summer migrations by *A. fabae* and accumulated temperatures. Since these relationships are so strong it is probably possible to predict also the timing of the mid-season crash, since this could be defined as the time when e.g. 90% of the summer migrant population has been captured.

Objective 4 Propose a way forward

Based on the findings of Objective 2 and Objective 3, a way forward is proposed:

1. Obtain data for all suction trap sites at which reasonable numbers of *A. fabae* have been captured.
2. Obtain comparable daily weather data from appropriate Met Office stations.
3. Use the suction trap data and weather data to develop a day-degree forecast for *A. fabae* to predict the start of the spring migration and the timing of different stages of the summer migration (i.e. when 1% caught, 10% caught, 50% caught, 90% caught etc).
4. Analyse these data for relationships that might help to predict abundance.
5. Develop a method of predicting abundance in the summer as early as possible from real-time suction trap data. This is probably feasible by using day-degrees to predict, for example, the date of 10% capture and then checking the real-time suction trap data to see how many aphids 10% capture equates to. This can then be used to predict abundance going forwards.
6. Determine whether relationships developed by Way *et al.* (1981) (Table 1.1), based on the numbers of aphids captured in suction traps, are likely to be of any practical use to spinach growers.
7. Incorporate the forecast into the HDC Pest Bulletin.

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Conclusions

There are some very strong relationships between the timing of migrations by *Aphis fabae* and temperature data and these could be developed into a day-degree forecast to predict the timing of migration and also predict the abundance of aphids in conjunction with real-time suction trap data. There is also the opportunity to determine whether relationships developed by Way *et al.* (1981), based on the numbers of aphids captured in suction traps, are likely to be of any practical use to spinach growers.

Knowledge and Technology Transfer

As this was a small project there was no budget for this activity.

Acknowledgements

We are extremely grateful to Richard Harrington and the team at the Rothamsted Insect Survey for supplying the data free of charge. We thank the HDC for supporting this work.

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