HDC Project FV 162e

ANNUAL REPORT

Outdoor lettuce: Refinement and field validation of forecasts for the aphid pests of lettuce foliage

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June 2000

Annual Report:	1999-2000
Project Number:	FV 162e
Project Title:	Outdoor lettuce: Refinement and field validation of forecasts for the aphid pests of lettuce foliage
Project Leader:	Dr R Collier
Location of Project:	HRI Wellesbourne, IACR Rothamsted
Project Co-ordinator:	Mr D Norman
Date project commenced:	1 May 1999
Date project to be completed:	30 April 2001
Key words:	Lettuce, aphids, forecasts, *Myzus persicae*, *Nasonovia euphorbiae*, *Macrosiphum euphorbiae*

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SCOPE AND OBJECTIVE

Aphids are the major pests of outdoor lettuce crops. There are three important species that colonise the foliage, the currant-lettuce aphid (*Nasonovia ribisnigri*), the peach-potato aphid (*Myzus persicae*) and the potato aphid (*Macrosiphum euphorbiae*). The purpose of this project is to refine and validate forecasts of the timing of key events in crop colonisation by these species, so that these can form part of an integrated approach to aphid control.

SUMMARY

- Data collected by the Rothamsted Insect Survey were used to determine relationships between the timing of aphid flight, aphid abundance and weather variables, using linear regression.
- Three aphid variables (date of first capture, mean date of first five captures, Log_{10} numbers caught to 1 July) for each of the three aphid species (*M. persicae*, *M. euphorbiae*, *N. ribisnigri*) were regressed on each of two weather variables (mean air temperature for January-February, mean air temperature for January-March), for each of 19 suction trap sites.
- The mean air temperature for January - February gave a stronger relationship than the mean air temperature for January - March on 61% occasions. The mean date of the first five captures gave a stronger relationship than the date of first capture on 69% occasions. Relationships with winter temperature were generally much stronger for *M. persicae* and *M. euphorbiae* than for *N. ribisnigri*.
- For each species, the relationship between winter temperature and the start of aphid flight differed between sites. However, any change in temperature had the same effect at all sites.
- The effects of site latitude and longitude were determined. At any given temperature there was a strong tendency for aphids to fly earlier and in greater numbers further south and east.
- Plots of lettuce for monitoring aphids were located at sites in Sussex, Kent, Warwickshire (HRI Wellesbourne), Lincolnshire, Norfolk and Yorkshire (HRI Stockbridge House). In general, five plots of approximately 300 plants were planted sequentially to cover the growing season.
- Sampling started in early May at most sites. Individual plots were sampled for several weeks, depending on the time of year and hence the rate of growth of plants. Each week, samples of 20 plants were cut and sent to HRI Kirton. Two plots at each location were sampled for much of the time (10 plants/plot), to ensure continuity.
- The aphids were removed from the plants, identified and counted. *Nasonovia ribisnigri* was the predominant species at all sites, except in Warwickshire, where *M. euphorbiae* was predominant.

- The dates on which the maximum numbers of aphids (adults + nymphs of all species) were found varied considerably between sites and ranged from 9 June - 18 October. The estimated dates of the first summer 'peak' and the timing of the mid-season 'crash' were more similar and ranged from 21 June – 9 August and 19 July - 23 August respectively.
- Estimates were made for each species, at each site, of the dates of key infestation events (the first alate and apterous adult, peak numbers of alates and apterae, the mid-season 'crash').
- The dates by which these events occurred at each site were compared with the mean air temperature for January – February, obtained from the weather station nearest to the monitoring site. Comparisons were made using linear regression. The times at which the first alate and apterous *M. persicae* and *M. euphorbiae* were found on plants were negatively correlated with winter temperature. For *M. euphorbiae*, the timing of mid-season 'crash' (alates and apterae) was also negatively correlated with winter temperature. None of the relationships with winter temperature were statistically significant for *N. ribisnigri*.
- Day-degree sums (base 4.4ºC) were accumulated from 1 February until 1 May, 1 June, 1 July and 1 August, using air temperature data from the weather station nearest to each monitoring site. The dates when peak numbers of alate *N. ribisnigri* were found on plants were positively correlated with day-degree sums accumulated to 1 May, 1 June, 1 July and 1 August. The timing of the alate 'crash' was positively correlated with day-degrees accumulated to 1 June.
- The effects of latitude and longitude determined from the Rothamsted Insect Survey data will be used to refine forecasts based on these relationships with weather data.

ACTION POINTS FOR GROWERS

- In the UK, peaks of aphid abundance on lettuce foliage occur in mid-summer and in the autumn, with a distinct period of low abundance in the intervening period. Whilst all three species contribute to the first peak, *N. ribisnigri* dominates in the autumn. However, the precise timing of the periods of high and low aphid abundance varies from region to region and year to year.
- Infestations of *M. persicae* and *M. euphorbiae* on lettuce occur earlier following a mild winter. Infestations by *N. ribisnigri* are not correlated with winter temperature, but are related to spring temperatures (accumulated day-degrees).
- Site location also affects the timing of infestation. Analysis of data collected by the Rothamsted Insect Survey has shown that at any given temperature, there is a tendency for aphids to fly earlier, and in greater numbers, further south and east.
- It should be possible to indicate in March when peak colonisation by *M. persicae* and *M. euphorbiae* is likely to occur. The forecast for *N. ribisnigri* is based on accumulated day-degrees from 1 February, so the accuracy of predictions will increase during the spring and early summer. However, correlations between colonisation by the other two species and *N. ribisnigri* might permit earlier prediction of *N. ribisnigri* infestations.

BENEFITS

Cost-benefit analysis

The outdoor lettuce crop is worth about £60M annually (MAFF Basic Horticultural Statistics for the UK, 1986-96). The presence of even small numbers of aphids in salad crops can lead to supermarket rejections.

Sprays to outdoor lettuce crops cost about £290/ha (Nix, 1998) and approximately half of these will be for aphid control (about £145/ha). Thus a 5% reduction in the number of treatments applied for aphid control to the 6,800 ha lettuce grown in the UK could be worth about £50,000 per year, depending on the costs of insecticide and treatment. This would give a cost-benefit relationship of 1:3 for a period of five years.

More importantly, if higher levels of insecticide resistance were to develop due to intensive use of a small number of insecticide compounds, some crops would be totally unmarketable. A loss of 5% of the marketable crop would be worth about £3M per year. This would give a cost-benefit relationship of 1:200 over a period of five years.

Other benefits

- The project will increase lettuce growers' knowledge of aphid life cycles and help them to anticipate periods of aphid colonisation.
- Advanced warning of periods of aphid colonisation should lead to better use of crop monitoring resources and to improved targeting of insecticide treatments. This should in turn lead to a reduced number of supermarket rejections due to the presence of aphids in produce.
- The project will provide the industry with validated forecasts of the timing of aphid attacks. These could be made available as regional forecasts or could be generated locally using growers' own weather stations, with the forecast models incorporated into a decision support system such as MORPH.
- Preliminary forecasts could be made available immediately to growers for initial assessment and validation and they could be supplied with refined forecasts, as they become available.
- Management systems which lead to targeted applications of lower numbers of sprays would be favoured highly by consumers and would have considerable benefits for the environment.

SCIENCE SECTION

INTRODUCTION

Aphids are the major pests of outdoor lettuce crops, which cover an area of about 6,800 ha each year (MAFF Basic Horticultural Statistics for the UK, 1986-96). There are four important pest aphid species. These are the lettuce root aphid (*Pemphigus bursarius*), and three species that colonise the foliage, the currant-lettuce aphid (*Nasonovia ribisnigri*), the peach-potato aphid (*Myzus persicae*) and the potato aphid (*Macrosiphum euphorbiae*).

The Pesticide Usage Survey Report for 1995 (Garthwaite *et al.*, 1995) indicates that each lettuce crop receives an average of 5.2 sprays for insect control. In 1995, a total area of 49,000 ha crop was treated with insecticide, of which only 3,500 ha were treated for specifically non-aphid pests. However this information was collected prior to the introduction of imidacloprid seed treatment.

Aphid control presents a number of problems for lettuce growers. Particular difficulties include:

- A limited choice of effective active ingredients.
- Insecticide resistance to several insecticide groups in *M. persicae*, *M. euphorbiae* and *N. ribisnigri.*
- The potential for development of resistance to other insecticide groups.
- Increasing pressure from processors, multiple retailers and consumers to justify and to reduce insecticide use.

However, there are future opportunities for more specific non-insecticidal methods of aphid control, including the development of lettuce varieties resistant to aphids and the use of entomopathogenic fungi incorporated into module compost for control of *P. bursarius*. There is, therefore, a requirement for a more integrated approach to aphid control, where specific control measures are targeted at particular species at certain stages in their life cycle. Early warning of the timing of aphid infestations would expedite this approach.

The phenology of the three main aphid species infesting lettuce foliage (*Myzus persicae*, *Macrosiphum euphorbiae*, *Nasonovia ribisnigri*) was investigated in MAFF LINK project P 131, FV 162 which was funded by MAFF, the HDC and Elsoms seeds. In this project, preliminary forecasts of aphid colonisation were developed, by establishing relationships between the timing of key infestation events and air temperatures. Key events considered included the start and peak of colonisation in early and late summer and the timing of the mid-season decline in aphid numbers (aphid ‘crash’).

For the two predominantly anholocyclic species (overwinter as nymphs or adults), *M. persicae* and *M. euphorbiae,* relationships were established between colonisation of lettuce crops and forecasts of aphid immigration developed by the Rothamsted Insect Survey. These forecasts use the relationship between the mean air temperature for January - February and the date when the first alate aphid is captured in suction traps each year (Harrington *et al.*, 1990). Richard Harrington and colleagues at IACR Rothamsted have shown that for *M. persicae,* the relationship with winter temperature changes with latitude (Harrington *et al.*, 1993). This may also be true for *M. euphorbiae*.

For the holocyclic species (overwinter as eggs), *N. ribisnigri,* a relationship was established between key infestation events and day-degrees above 0^{o} accumulated from 1 February each year. The forecast for *N. ribisnigri* was developed solely from field data collected during LINK project P 131, FV 162.

Analysis of monitoring data collected during the LINK project also showed that each year, the timing of the mid-season decline in aphid numbers (aphid 'crash'), was similar in all three species of foliage-feeding aphid (*M. persicae, M. euphorbiae, N. ribisnigri*). The aphid 'crash' appeared to occur at about the same time in all lettuce plots at a single location, regardless of the development stage of the crop.

Forecasts of the timing of peak populations of *M. persicae* and *M. euphorbiae* on ware potato crops have been developed using mean air temperatures for January to March. The forecast models were improved by the inclusion of mean May air temperatures (MAFF Project HP0103; Parker, 1998).

EXPERIMENTAL

Objective 1. Use data from the Rothamsted Insect Survey to refine forecasts for aphid pests (*M. persicae*, *M. euphorbiae*, *N. ribisnigri*) of lettuce foliage.

1.1 Extract data on *M. persicae*, *M. euphorbiae* and *N. ribisnigri* from historical data sets.

The date of the first capture, mean date of the first five captures and numbers caught up to July 1^{st} (Log_{10}) were extracted for each species for the following sites (Figure 1) and years: Rothamsted (1965-1998); Wye (1967-1997); Broom's Barn (1965-1998); Newcastle (1967-1997, not 1991); Dundee (1967-1997); East Craigs (1969-1997); Starcross (1970-1997); Elgin (1971-1997); Hereford (1973-1997); Preston (1975-1998, not 1983); Ayr (1975-1997, not 1993); Writtle (1976-1997); Kirton (1981-1997); Long Ashton (1970-1997, not 1989-1992); High Mowthorpe (1967-1988); Silwood (1968-1988); Rosewarne (1969-1988); Aberystwyth (1969-1988, not 1970) and Shardlow (1971-1988). The years reflect availability of both aphid and weather data. Mean temperatures for the periods January to February and January to March each year were extracted for each site, or the nearest available weather station if not at the trap site, from the BBSRC 'ARCMET' database.

1.2 Determine relationships between the timing of aphid flight, aphid abundance and appropriate weather variables using regression and other statistical techniques.

Three aphid variables (date of first capture, mean date of first five captures, Log_{10} numbers caught to 1 July) for each of the three aphid species (*M. persicae*, *M.*

euphorbiae, *N. ribisnigri*) were regressed on each of the two weather variables (mean air temperature for January-February, mean air temperature for January-March), for each of 19 suction trap sites (3 x 3 x 2 x 19 = 342 regressions). For each aphid versus weather combination, an analysis was done to see whether the relationship was best described by separate lines for each site, a single line combining all sites, or parallel lines (i.e. with the same slope for each site but with a different intercept on the aphid axis).

The percent variance accounted for in each individual regression is shown in Table 1a (*Myzus persicae*), Table 1b (*Macrosiphum euphorbiae*) and Table 1c *(Nasonovia ribisnigri*). The mean air temperature for January - February gave a stronger relationship than the mean temperature for January - March on 105 out of 171 occasions. The mean date of the first five captures gave a stronger relationship than the date of first capture on 79 out of 114 occasions.

Relationships were generally very much stronger for *M. persicae* and *M. euphorbiae* than for *N. ribisnigri*. This is probably mainly due to *N. ribisnigri* overwintering in the egg stage and the other two overwintering in the active parthenogenetic stage. The egg is much more cold tolerant than the active stages, and the active stages are able to take advantage of warmer conditions with bursts of development and reproduction, whereas the eggs are in diapause and cannot. Numbers of *N. ribisnigri* in samples were generally very much smaller than of the other two species.

The percentage variance accounted for by single line, parallel line and separate line models is shown in Table 1d. A single line was never the best description. A parallel line accounted for more variance than separate lines on 9 out of 18 occasions, but the results were always very similar, differing by a maximum of 2.1% and a mean of 0.4%. It is therefore sensible to adopt the more parsimonious parallel line models, meaning that, for a given aphid species, any given *change* in temperature has the same effect at all sites, but that at any given temperature, the aphid variable is site-specific.

1.3 Determine the effect of latitude on these relationships

This objective was extended to include longitude. Intercepts on the aphid axis were extracted from the 18 parallel regression models described above and themselves regressed separately on latitude and on longitude. The co-ordinates of each site are shown in Table 2.

The variance accounted for in these relationships is shown in Table 3. At any given temperature there was a strong tendency for aphids to fly earlier and in greater numbers further south and east. Earliness and numbers may be artifactually related because the probability of detection in the trap is greater when numbers are larger. Rosewarne was a clear outlier in the latitude regressions, the influence of its westerliness dominating over the influence of its southerliness. The latitude regressions were therefore also run excluding Rosewarne.

Objective 2. Obtain field-monitoring data from geographically separate areas of outdoor lettuce production to validate refined forecasts.

2.1 Locate sites in Sussex, Kent, Warwickshire (HRI Wellesbourne), Lincolnshire, Norfolk and Lancashire (HRI).

David Langmead (Sussex), Intercrop (Kent), Jarrow Produce (Essex), J. E. Piccaver & Co. (Lincolnshire) and County Crops (Lancashire) agreed to participate in the project. Subsequently, County Crops were unable to participate and plots were planted at HRI Stockbridge House (Yorkshire) instead. As a consequence, sampling was delayed at Stockbridge House.

2.2 Set up plots to monitor aphid pests of lettuce by making five sequential plantings of iceberg lettuce (cv Saladin, insecticide-free) at each site. Plot size to be approximately 300 plants. Plot dimensions will depend on individual growers (HRI).

Most growers made five sequential plantings of lettuce; Intercrop made 11 plantings. In general, the lettuce varieties were chosen and the plants raised by individual growers. All the plants were raised from insecticide free seed. The plants grown at HRI Wellesbourne and David Langmead were cv Saladin and were propagated at HRI (Wellesbourne or Kirton).

2.3 Arrange for a sample of plants (10-20) to be cut each week by HRI staff or by the grower. Samples cut by growers will be sent in a box (next day delivery) to HRI (HRI).

Sampling started by early May at most sites.

Monitoring site		First sample taken on:
1	Sussex	5 May
2	Kent	4 May
3	Essex	31 May
4	Warwickshire	29 Apr
5	Lincolnshire	28 Apr
6	Yorkshire	6 Aug (late start due to difficulties with initial location)

Individual plots were sampled for several weeks, depending on the time of year and hence the rate of growth of plants. Two plots at each location were sampled for much of the time, to ensure continuity. Each week, samples of 20 plants were cut and sent to HRI Kirton (10 plants/plot when two plots were sampled). A typical sampling layout is shown in Appendix 1. Samples were delivered by post or carrier.

2.4 Identify and count aphids from samples (HRI).

Aphids were removed from the lettuce foliage at HRI Kirton, counted (but not identified) and preserved in 70% alcohol for later identification at HRI Wellesbourne. Adult aphids were identified to species, the nymphs were counted. In addition, non-aphid species of invertebrate were counted and identified at least to Order and sometimes to species. Growers were informed (by return) of the numbers of aphids (and non-aphid pests) found on plants.

2.5 Collate monitoring data (HRI).

The monitoring data were collated at HRI and summarised graphically (Figures 2-3). Scales differ considerably between individual graphs. In general, there were two peaks of aphid abundance, separated by a period when numbers were low (the mid-season 'crash').

Objective 3. Validate refined forecasts for the aphid pests of lettuce.

3.1 Summarise monitoring data and identify key infestation events at each site in each year (start of colonisation, peak of colonisation, timing of aphid 'crash') (HRI).

The maximum numbers of alate and apterous aphids/plant found at each site are shown in Table 4. *Nasonovia ribisnigri* was the predominant species at all sites except in Warwickshire, where *M. euphorbiae* was predominant.

Not surprisingly, nymphs were more numerous than adult aphids. Although it was not possible to identify the nymphs to species, their numbers were correlated with the numbers of adult aphids found on the plants. The maximum number of aphids/plant found at each site and the dates when these were found are shown in Table 4. The dates on which maximum numbers were found varied considerably between sites and ranged from 9 June - 18 October. The estimated dates of the first summer 'peak' and of the mid-season 'crash' were more similar and ranged from 21 June – 9 August and 19 July - 23 August for the two estimates respectively.

The dates on which the first alate and apterous adult of each species were found at each site, the dates when alates and apterae were most abundant, and estimates of the timing of the mid-season 'crash', are shown in Table 6.

3.2 Validate refined aphid forecasts by correlating forecast predictions with the timing of key infestation events (HRI).

The data collected in 1999 were added to the data set collected in MAFF LINK project P 131, FV 162 (1994-97) (Tatchell *et al.*, 1998) to verify relationships between key infestation events and winter temperature (mean air temperature for January - February). No account was taken of the effects of latitude and longitude established in Objective 1.3. This forms part of the second year's work.

The timing of each infestation event at each site was compared with the mean air temperature for January – February obtained from the weather station nearest to the monitoring site. Comparisons were made using linear regression. The percentage variance accounted for by each of the regressions is shown in the Table 7. The times at which the first alate and apterous *M. persicae* and *M. euphorbiae* were found on plants were negatively correlated with winter temperature. For *M. euphorbiae*, the timing of mid-season 'crash' (alates and apterae) was also negatively correlated with winter temperature (Figures 4-5). None of the relationships with winter temperature were statistically significant for *N. ribisnigri*.

For *N. ribisnigri,* a relationship had been established previously between key infestation events and day-degrees accumulated from 1 February each year (Tatchell *et al*., 1998). Since the threshold temperature for development of *N. ribisnigri* is unknown, a base temperature of 0°C was used. However, this base temperature may be too low.

The data collected in 1999 were added to the data set collected in the LINK project (1994-97) to validate relationships between key infestation events and accumulated day-degrees above a base temperature of 4.4°C. This is the threshold temperature for development of the lettuce root aphid (*Pemphigus bursarius*) (Dunn, 1959). Although the two species of aphid are not related closely, *P. bursarius* is another pest of lettuce and is also holocyclic, overwintering on poplar trees (*Populus* spp.).

The dates when peak numbers of alate *N. ribisnigri* were found on plants were positively correlated with day-degree sums (base 4.4°C) accumulated to 1 May, 1 June, 1 July and 1 August. The alate 'crash' was positively correlated with day-degrees accumulated to 1 June (Figure 6). No account was taken of the effects of latitude and longitude established in Objective 1.3. This forms part of the second year's work.

DISCUSSION

During 1999, *N. ribisnigri* was the predominant species at all but one of the monitoring sites, confirming previous studies in north west Europe (Aarts *et al*., 1999; Reinink & Dieleman, 1993; Tatchell *et al*., 1998). In general, there were two peaks of aphid abundance on lettuce foliage, with a distinct period of low abundance in the intervening period, again confirming previous studies (Aarts *et al*., 1999; Tatchell *et al*., 1998). However, the precise timing of the periods of high and low aphid abundance varied from site to site; their timing also varies from year to year (Tatchell *et al*., 1998).

Aphid abundance varied between sites and where numbers were low it was sometimes difficult to estimate when the 'peak' or the 'crash' occurred. In future, it may be possible to combine data to estimate these parameters more accurately. For example, records of alates and apterae could be combined to estimate when infestations of each species 'peaked' or 'crashed'. Similarly, since there is evidence that the mid-season 'crash' occurs simultaneously in all species (Tatchell *et al*., 1998), it may be possible to use records for all species (including nymphs) to estimate the timing of the 'crash'.

Previous analyses of long-term aphid monitoring data collected by the Rothamsted Insect Survey have shown that for species such as *M. persicae* and *M. euphorbiae*, which have predominantly anholocyclic life cycles in the UK, the time that the first alate is found in suction trap samples is negatively correlated with winter temperature (Harrington *et al*., 1990). There is also a positive correlation between winter temperature and aphid abundance during the first half of the year. These analyses have now been extended, and the results presented here show that in general, the relationship with the mean air temperature for January - February is stronger than that with the mean temperature for January - March. Not surprisingly, the mean date of capture of the first five aphids is also negatively correlated with winter temperature and, in general; this relationship is stronger than that with the capture of the first aphid.

Whilst the relationship with winter temperature is particularly pronounced for species such as *M. persicae* and *M. euphorbiae*, such relationships are much weaker for holocyclic species such as *N. ribisnigri* (Harrington *et al*., 1990). Early season activity is likely to be related more closely to spring temperatures (Thomas *et al*., 1983), through their effects on aphid development after egg hatch. Consequently, spring temperatures are more likely to predict the timing of infestation by *N. ribisnigri*, as shown by correlations between key infestation events and accumulated day-degrees.

Previous studies have shown that the linear relationship between the date on which the first *M. persicae* is captured, and winter temperature, varies between sites (Harrington *et al.*, 1993). In general, the fitted lines are parallel, but with different intercepts, such that for any given mean winter temperature, the first aphid will be captured later further north. The effects of latitude and longitude have now been determined for all three species. At any given temperature there is a strong tendency for aphids to fly earlier and in greater numbers further south and east. Thus a factor associated with latitude, other than temperature, may be influencing the timing of immigration. One of the main aims of the second year of this project is to determine whether the relationships between key infestation events on lettuce crops and winter temperature can be improved if the effects of latitude and longitude are taken into account.

INTERIM CONCLUSIONS

The monitoring data collected in 1999 confirmed that peaks of aphid abundance on lettuce foliage occur in mid-summer and in the autumn, with a distinct period of low abundance in the intervening period. Whilst all three species of aphid contribute to the first peak, *N. ribisnigri* dominates in the autumn. However, the precise timing of the periods of high and low aphid abundance varies from region to region and year to year.

Infestations of *M. persicae* and *M. euphorbiae* on lettuce occur earlier following a mild winter. Analyses of Rothamsted Insect Survey data showed that site location also affects the timing of infestation. At any given temperature there is a tendency for aphids to fly earlier, and in greater numbers, further south and east. Infestations by *N. ribisnigri* are not correlated with winter temperature, but are related to spring temperatures (accumulated day-degrees).

It should be possible to indicate in March when peak colonisation by *M. persicae* and *M. euphorbiae* is likely to occur and to incorporate the effects of site location (latitude and longitude) into a temperature-based model.

The forecast for *N. ribisnigri* is based on accumulated day-degrees from 1 February, so the accuracy of predictions will increase during the spring and early summer. However, correlations between colonisation by the other two species and *N. ribisnigri* may permit earlier prediction of *N. ribisnigri* infestation.

ACKNOWLEDGEMENTS

We are especially grateful to the lettuce growers who provided lettuce plots and sampled the plants for the project, and to the HDC for funding this work. Thanks also to Sally Minns, Liz Vice, Sue Sime and Kelly Reynolds for technical assistance. Kath Phelps and Suzanne Clark provided statistical advice.

REFERENCES

Aarts, R., Schut, J.W., Driessen, R. & Reinink, K. (1999). Integrated control of aphids on lettuce varieties resistant to *Nasonovia ribisnigri*. *Mededelingen Faculteit Landbouwkundige en Toegepaste Biologische Wetenschappen* 64/3a, 11-15.

Dunn, J.A. (1959). The biology of lettuce root aphid. *Annals of Applied Biology* **47:** 475-491.

Garthwaite, D.G., Thomas, M.R., Hart, M.J. & Wild, S. (1995). Pesticide Usage Survey Report 134, Outdoor Vegetable Crops in Great Britain 1995. *Ministry of Agriculture, Fisheries and Food & Scottish Office Agriculture, Environment & Fisheries Department.*

Harrington, R., Tatchell, G.M. & Bale, J.S. (1990). Weather, life-cycle strategy and spring populations of aphids. *Acta Phytopathologica et Entomologica Hungarica* **25**, 423-432.

Harrington, R., Bale, J.S. & Tatchell, G.M. (1993). Aphids in a changing climate. In: Insects in a changing environment. *R. Harrington & N.E. Stork (Editors). 17th Symposium of the Royal Entomological Society of London 7-10 September 1993, Academic Press, London.*

Nix, J. (1998). Farm Management Pocketbook. *Wye College, University of London. 29th edition (1999).*

Parker, W.E. (1998). Forecasting the timing and size of aphid populations (*Myzus persicae* and *Macrosiphum euphorbiae*) on potato. *Aspects of Applied Biology* **52**, 31-38.

Tatchell, G.M., Ellis, P.R., Collier, R.H., Chandler, D., Mead, A., Wadhams, L.J, Parker, W.E., Blood Smyth, J. & Vice, E. W. (1998). Integrated pest management of aphids on outdoor lettuce crops. *Final Report 1994-98 MAFF LINK Project P 131, HDC Project FV 162. 77 pp.*

Thomas, G.G., Goldwin, G.K. & Tatchell, G.M. (1983). Associations between weather factors and the spring migration of the damson-hop aphid, *Phorodon humuli*. *Annals of Applied Biology* **102,** 7-17.

TABLES

Table 1a The percent variance accounted for in each individual regression for *Myzus persicae*.

SITES	Log_{10} Number to Week 26		1st Capture		Mean of First 5 Captures	
	Jan-Feb	Jan-Mar	Jan-Feb	Jan-Mar	Jan-Feb	Jan-Mar
Rothamsted	62.4	53.6	76.5	71.1	76.8	68.2
Wye	59.4	50.5	15.6	6.1	58.6	47.1
Brooms Barn	59.0	57.2	59.7	56.7	69.4	64.7
Newcastle	54.1	51.6	49.0	41.5	59.1	47.5
Dundee	34.9	34.3	28.6	35.2	48.2	52.5
East Craigs	57.1	51.9	64.5	62.8	64.8	58.7
Starcross	49.7	34.0	32.8	20.1	41.3	27.9
Elgin	19.4	18.5	8.9	13.8	21.0	13.7
Hereford	61.1	51.7	63.7	59.6	66.5	55.5
Preston	52.2	45.4	0	0	45.0	44.8
Ayr	43.4	38.6	54.1	53.1	71.2	59.8
Writtle	67.7	49.5	56.1	50.4	74.2	72.2
Kirton	68.4	57.1	55.8	58.0	67.0	62.7
Long Aston	64.9	44.2	60.4	53.2	66.2	60.4
High Mowthorpe	18.3	11.4	18.7	8.2	8.0	0
Silwood	52.6	40.0	17.8	20.7	48.4	48.1
Rosewarne	6.6	1.8	3.6	0	0	0
Aberystwyth	50.6	26.3	5.6	3.2	55.2	36.0
Shardlow	44.1	29.6	57.0	47.7	51.3	35.6

Table 1b The percent variance accounted for in each individual regression for *Macrosiphum eurphorbiae*.

SITES	Log_{10} Number to Week 26		1st Capture		Mean of First 5 Captures	
	Jan-Feb	Jan-Mar	Jan-Feb	Jan-Mar	Jan-Feb	Jan-Mar
Rothamsted	46.5	43.0	27.9	39.5	37.4	42.8
Wye	39.8	28.6	14.4	17.6	35.5	31.7
Brooms Barn	35.8	43.6	48.0	57.9	49.1	59.4
Newcastle	24.8	20.1	40.2	37.2	40.1	34.9
Dundee	30.6	29.3	25.9	33.2	35.5	37.3
East Craigs	51.0	55.5	39.0	48.5	45.1	55.4
Starcross	36.5	32.7	12.6	25.2	32.9	38.3
Elgin	27.2	18.0	24.1	15.2	26.9	16.0
Hereford	51.0	42.2	48.5	52.1	52.0	56.0
Preston	64.0	48.6	52.2	56.9	55.7	54.3
Ayr	34.1	31.1	33.2	34.5	54.3	57.8
Writtle	59.6	50.0	44.5	47.4	46.4	50.9
Kirton	59.3	55.2	50.4	57.3	58.8	64.6
Long Aston	32.8	14.6	12.6	2.7	18.8	6.3
High Mowthorpe	24.6	19.4	22.9	26.4	33.0	27.3
Silwood	67.1	51.9	38.0	28.1	49.3	41.9
Rosewarne	0	0	3.4	0.1	0	0
Aberystwyth	45.3	52.1	48.7	55.7	46.4	60.5
Shardlow	13.6	2.0	17.1	10.8	17.5	6.9

Table 1c The percent variance accounted for in each individual regression for *Nasanovia ribisnigri*.

SITES	Log_{10} Number to Week 26		1st Capture		Mean of First 5 Captures	
	Jan-Feb	Jan-Mar	Jan-Feb	Jan-Mar	Jan-Feb	Jan-Mar
Rothamsted	0	0	0	0	0	0
Wye	11.0	8.8	1.2	3.5	9.3	7.4
Brooms Barn	5.3	2.3	5.5	4.7	1.5	0
Newcastle	0	0	0	0	-	-
Dundee	2.3	1.2	7.1	7.0	6.3	14.8
East Craigs	0.3	0.2	0.7	6.0	29.3	30.6
Starcross	21.0	7.0	10.1	1.0	13.1	1.4
Elgin	16.9	16.4	3.8	3.9	35.1	23.9
Hereford	0	0	0	0	4.3	4.6
Preston	0	0	0	0	13.2	13.8
Ayr	5.0	1.8	22.6	10.1	-	-
Writtle	17.3	14.6	26.3	28.8	28.1	27.3
Kirton	27.5	33.5	58.7	61.9	30.7	39.6
Long Aston	0	0	0	0	24.1	9.3
High Mowthorpe	17.7	6.3	12.5	1.7	0	0
Silwood	34.3	20.1	18.2	2.4	29.4	16.4
Rosewarne	0	0	0	0	0	0
Aberystwyth	8.9	0.3	13.0	6.1	50.4	42.1
Shardlow	0	0	9.4	11.7	0	0

Table 1d The percent variance accounted for by single line, parallel line and separate line models.

	Log_{10} Number to Week 26		**1st Capture**		**Mean of First 5 Captures**	
	Jan-Feb	**Jan-Mar**	**Jan-Feb**	**Jan-Mar**	**Jan-Feb**	**Jan-Mar**
M. persicae						
Single Line	31.3	29.8	26.2	26.2	31.2	29.9
Parallel	67.2	61.9	52.9	50.4	68.7	64.1
Separate Lines	69.3	63.0	53.2	50.3	68.8	63.8
M. euphorbiae						
Single Line	30.8	30.4	30.1	35.3	32.0	35.5
Parallel	59.5	56.2	53.5	55.5	61.9	62.3
Separate Lines	59.4	56.4	53.1	55.5	61.9	62.8
N. ribisnigri						
Single Line	5.2	4.4	4.7	4.8	10.9	9.0
Parallel	40.4	38.5	29.6	28.5	32.3	28.9
Separate Lines	40.6	38.2	29.3	28.1	31.9	28.5

Table 2. Latitude and longitude of suction trap locations.

Site	Latitude	Longitude
Rosewarne	50° 13	5° 18
Starcross	50° 37	3° 27
Littlehampton	50° 49	0° 31
Wye	51° 11	0° 56
Silwood	51° 24	0° 38
Long Ashton	51° 25	2° 40
Writtle	51° 44	0° 25
Rothamsted	51° 48	0° 21
Broom's Barn	52° 15	0° 34
Aberystwyth	52° 26	4° 0
Shardlow	52° 52	1° 20
Kirton	52° 56	0° 4
Hereford	52° 7	2° 38
Preston	53° 51	2° 45
Tadcaster	53° 51	1° 20
High Mowthorpe	54° 6	0° 38
Newcastle	55° 12	1° 40
Ayr	55° 28	4° 34
East Craigs	55° 56	3°18
Dundee	56° 27	3° 4
Elgin	57° 38	3° 21

Table 3. Variance accounted for in regression of residuals from aphid vs temperature regressions on latitude (with and without Rosewarne) and longitude. (J-F = Jan-Feb temperature, J-M = Jan-Mar temperature)

			% Variance		
			Latitude	**Lat. Minus Rosewarne**	**Longitude**
M. persicae	Log to Wk 26	J-F	11.7	43.3	62.7
		J-M	10.7	42.6	61.3
	1st Flight	J-F	32.8	69.5	30.9
		J-M	30.7	67.7	28.3
	Mean 1st 5	J-F	30.5	63.3	41.5
		J-M	30.0	63.3	39.1
M. euphorbiae	Log to Wk 26	J-F	14.4	43.9	24.6
		J-M	12.8	42.5	22.3
	1st Flight	J-F	31.5	54.7	12.1
		J-M	27.3	53.4	12.0
	Mean 1st 5	J-F	30.3	52.5	13.5
		J-M	27.1	50.6	12.5
N. ribisnigri	Log to Wk 26	J-F	29.3	46.8	20.9
		J-M	31.1	47.5	18.8
	1st Flight	J-F	34.8	51.5	28.4
		J-M	35.2	51.5	27.0
	Mean 1st 5	J-F	7.1	21.2	34.2
		J-M	5.7	18.1	29.8

Table 4. The maximum numbers of alates and apterae/plant found at each site.

Site	*M. persicae*		*M. euphorbiae*		*N. ribisnigri*	
	Alates	**Apterae**	**Alates**	**Apterae**	**Alates**	**Apterae**
Sussex	0.8	5.6	0.3	0.3	10.4	4.2
Kent	0.5	3.7	0.5	0.9	11.3	6.2
Essex	0.3	2.1	0.4	2.0	14.6	23.9
Warwicks	1.2	3.9	2.5	13.5	1.8	1.9
Lincs	0.3	2.5	2.0	2.4	8.4	4.2
Yorks	0.1	0.4	0.1	0.3	4.0	4.3

Table 5. The maximum numbers of aphids (all species) found at each site, the dates when maximum numbers were found, the estimated dates of the first 'peak' and mid-season 'crash'.

Site	**Max no. aphids/plant**	**Date max no. found**	**Estimated date of first peak**	**Estimated date of mid-season crash**
Sussex	95.7	12-Jul	02-Aug	16-Aug
Kent	126.5	02-Aug	09-Aug	23-Aug
Essex	354.1	21-Jun	21-Jun	19-Jul
Warwicks	180	09-Jun	02-Jul	03-Aug
Lincs	69.7	18-Oct	09-Aug	16-Aug
Yorks	53.3	06-Sep	-	-

Table 6. Estimated dates of key events in the phenology of the three aphid species at the six sites (up to an including the mid-season 'crash').

	First sample	**First alate**	**First aptera**	**Peak no. alates**	**Peak no. apterae**	**'Crash' alates**	**'Crash' apterae**
M. persicae							
Sussex	05-May	10-May	18-May	-	15-Jun	02-Aug	02-Aug
Kent	04-May	17-May	11-May	05-Jul	05-Jul	26-Jul	12-Jul
Essex	31-May	31-May	31-May	21-Jun	15-Jun	15-Jul	19-Jul
Warwicks	29-Apr	05-May	20-May	06-Jul	02-Jul	27-Jul	23-Jul
Lincs	28-Apr	02-Jun	16-Jun	30-Jun	30-Jun	13-Jul	13-Jul
Yorks	6 Aug	-	-	-	-	-	-
M. euphorbiae							
Sussex	05-May	10-May	10-May	29-Jun	-	19-Jul	26-Jul
Kent	04-May	11-May	04-May	12-Jul	05-Jul	19-Jul	26-Jul
Essex	31-May	31-May	31-May	21-Jun	21-Jun	07-Jul	07-Jul
Warwicks	29-Apr	05-May	05-May	06-Jul	02-Jul	27-Jul	03-Aug
Lincs	28-Apr	05-May	19-May	06-Jul	06-Jul	20-Jul	02-Aug
Yorks	6 Aug	-	-	-	-	-	-
N. ribisnigri							
Sussex	05-May	08-Jun	22-Jun	02-Aug	02-Aug	09-Aug	09-Aug
Kent	04-May	07-Jun	07-Jun	-	-	-	-
Essex	31-May	31-May	31-May	07-Jul	21-Jun	19-Jul	19-Jul
Warwicks	29-Apr	20-May	13-Aug	-	-	-	-
Lincs	28-Apr	05-May	26-May	-	-	-	-
Yorks	6 Aug	-	-	-	-	-	-

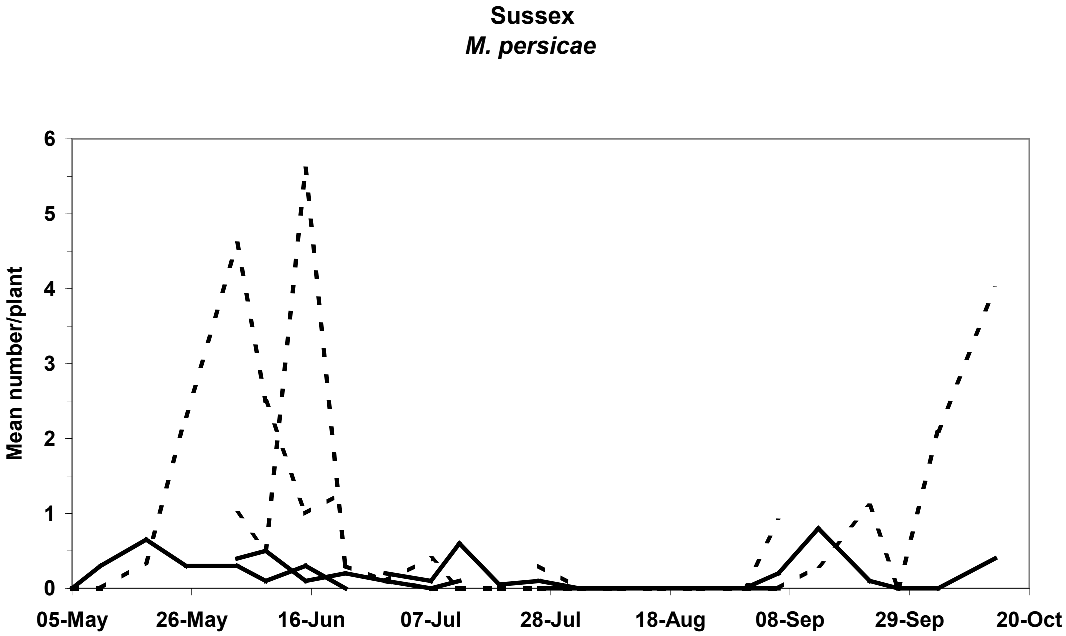
Table 7. Correlations between the timing of key infestation events and temperature. Correlations for *M. persicae* and *M. euphorbiae* used the mean air temperature for January - February, those for *N. ribisnigri* used accumulated day-degrees (base 4.4°C) from 1 February to 1 June. Data collected during 1994-97 and 1999 were combined. (Effects significant at the nominal 0.05, 0.02 and 0.01 levels are shown).

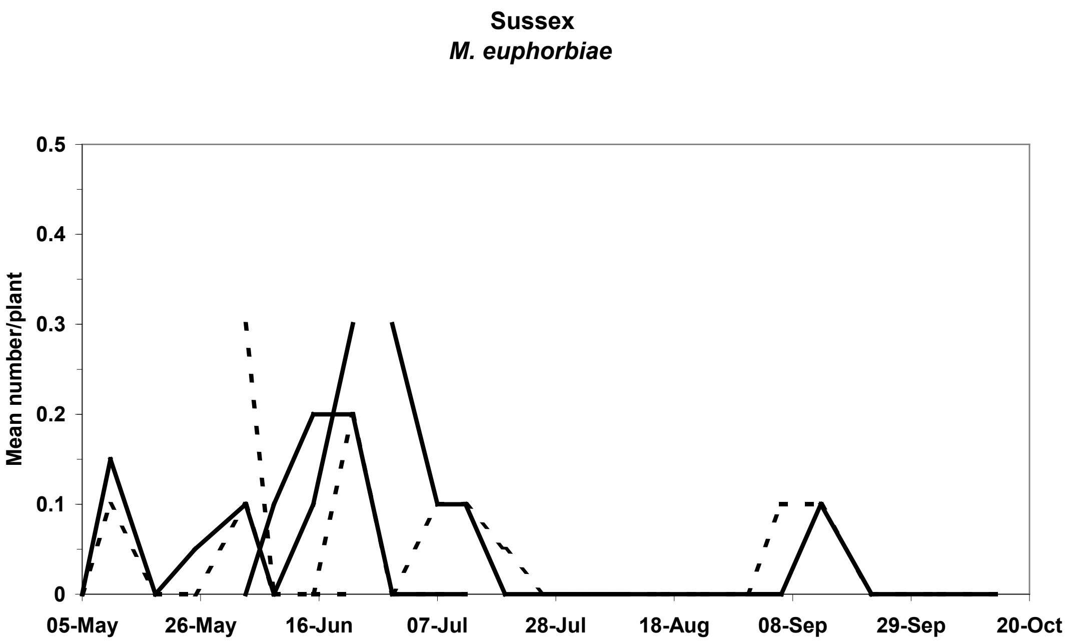
	First alate	**First aptera**	**Peak alate**	**Peak aptera**	**Crash alate**	**Crash aptera**
M. persicae						
No. sites	12	16	11	16	14	16
Percent variance accounted for	0.5649	0.3606	0.0142	0.2426	0.0307	0.0727
Significance level	<0.01	<0.02				
M. euphorbiae						
No. sites	12	15	17	16	17	17
Percent variance accounted for	0.5678	0.5213	0.0988	0.0918	0.3624	0.2548
Significance level	<0.01	<0.01			<0.02	<0.05
N. ribisnigri						
No. sites	16	16	13	14	14	14
Percent variance accounted for	0.137	0.0589	0.4264	0.1726	0.2838	0.0754
Significance level			<0.02		<0.05	

FIGURES

Figure 1. Map showing locations of Rothamsted Insect Survey suction traps.

Figure 2. The numbers of aphids found on untreated lettuce plants in 1999. (Solid lines = alates, dashed lines = apterae).





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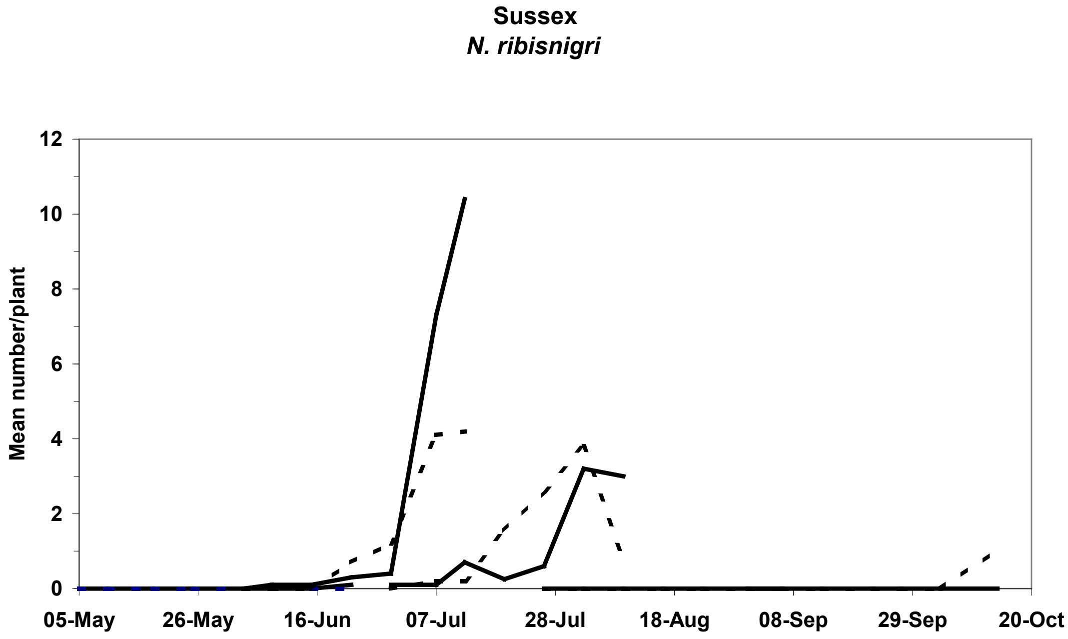

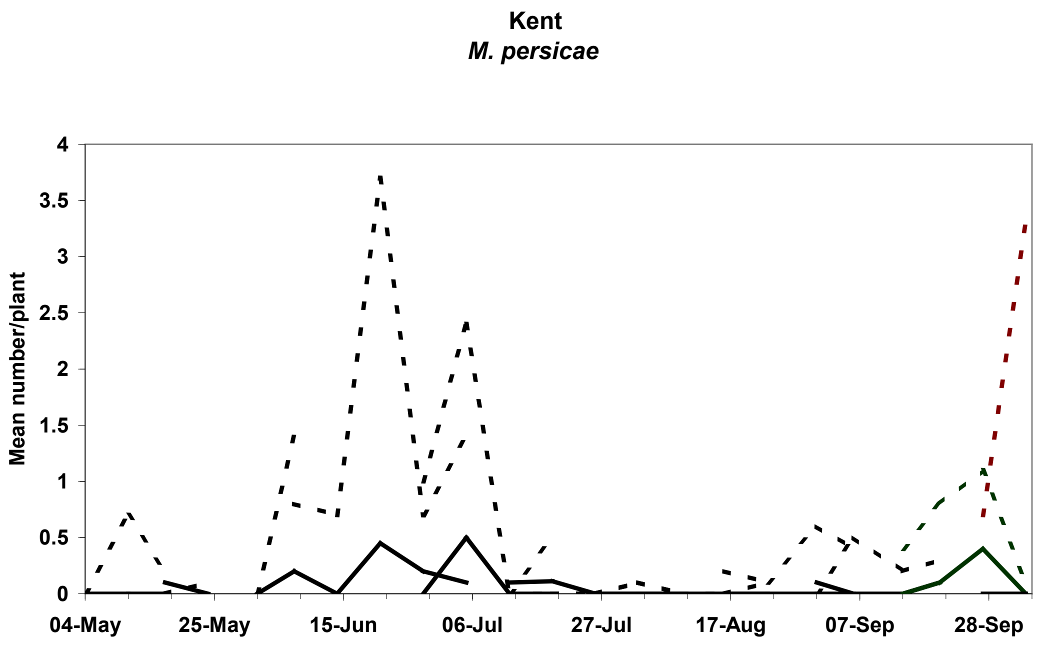

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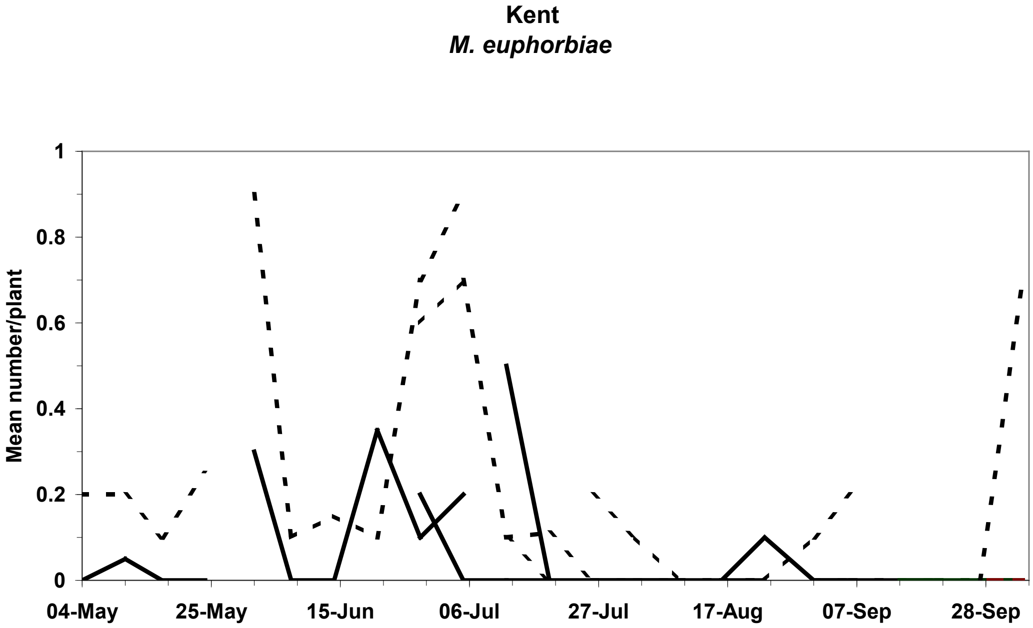

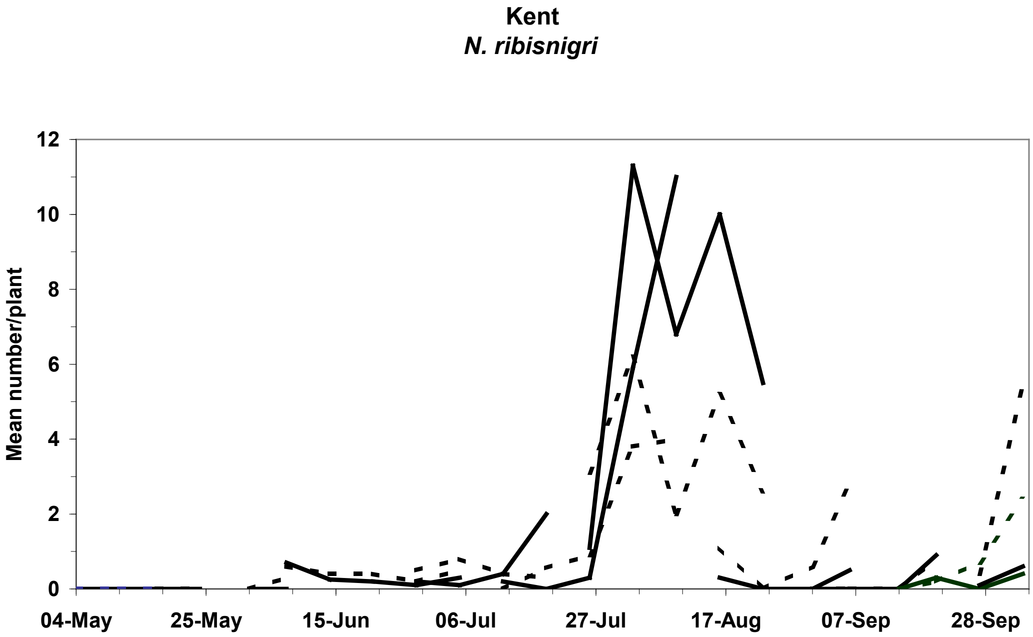

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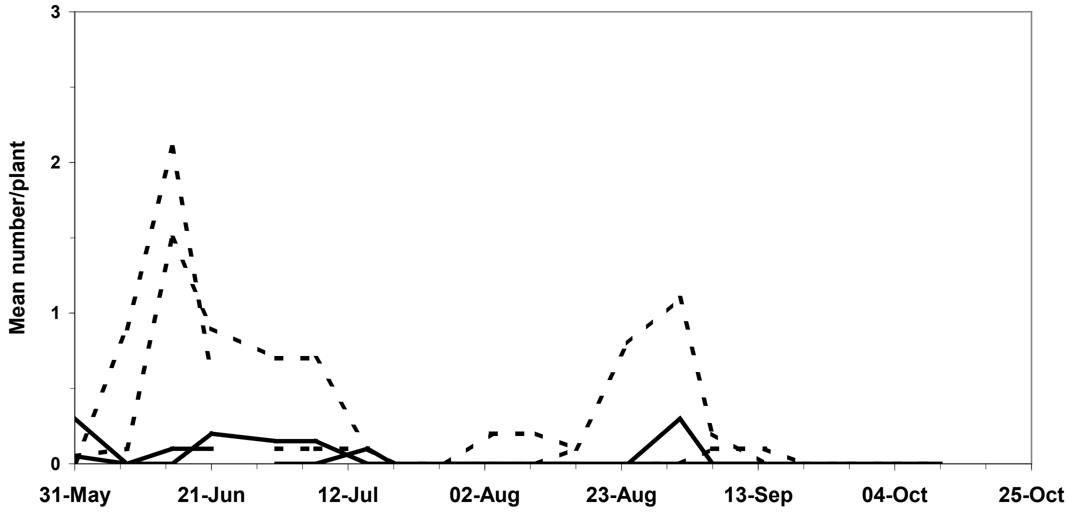
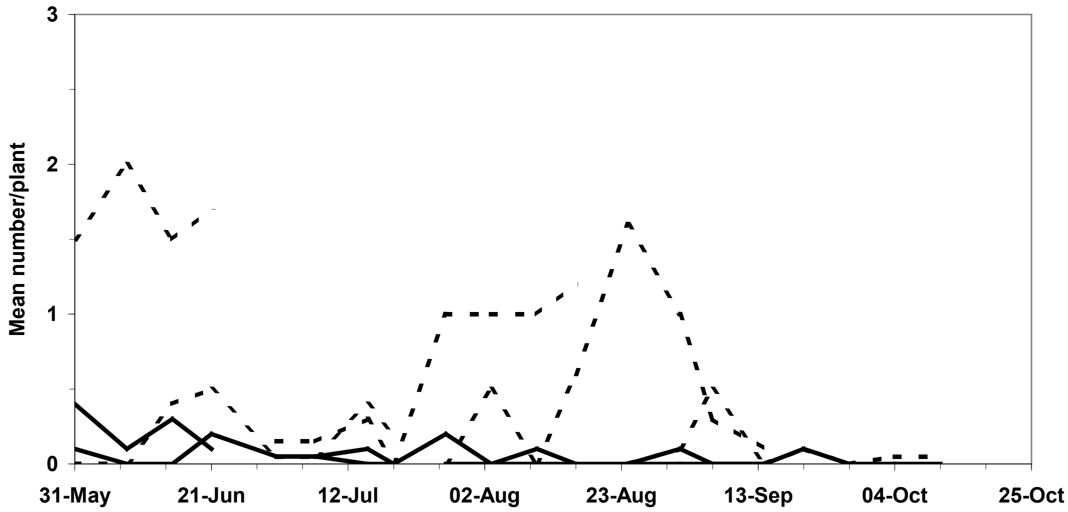
Essex
M persicae



Essex
M euphorbiae



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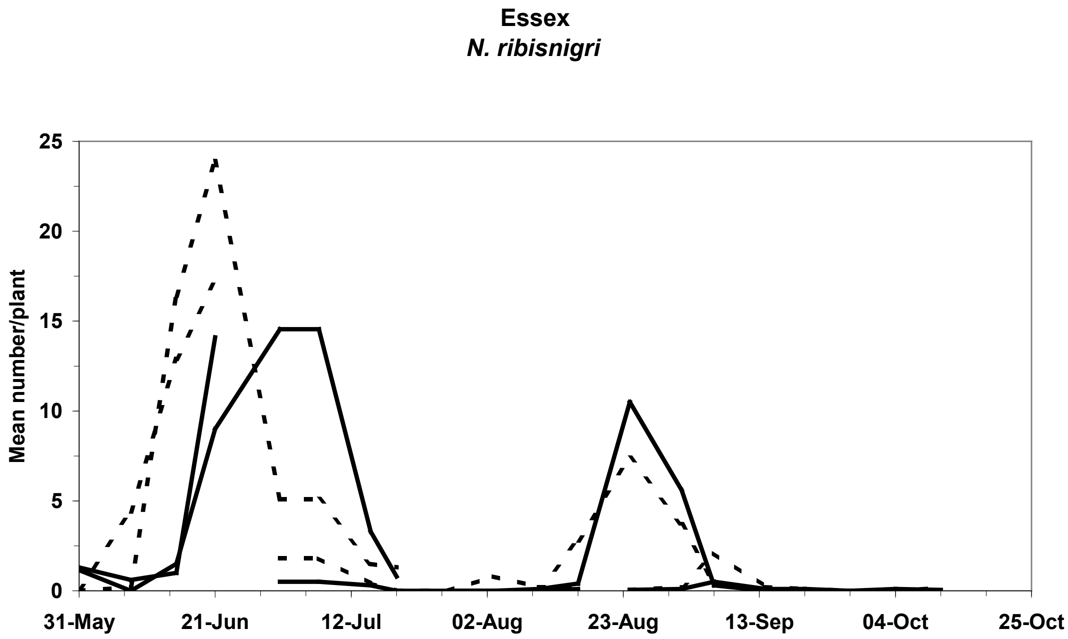

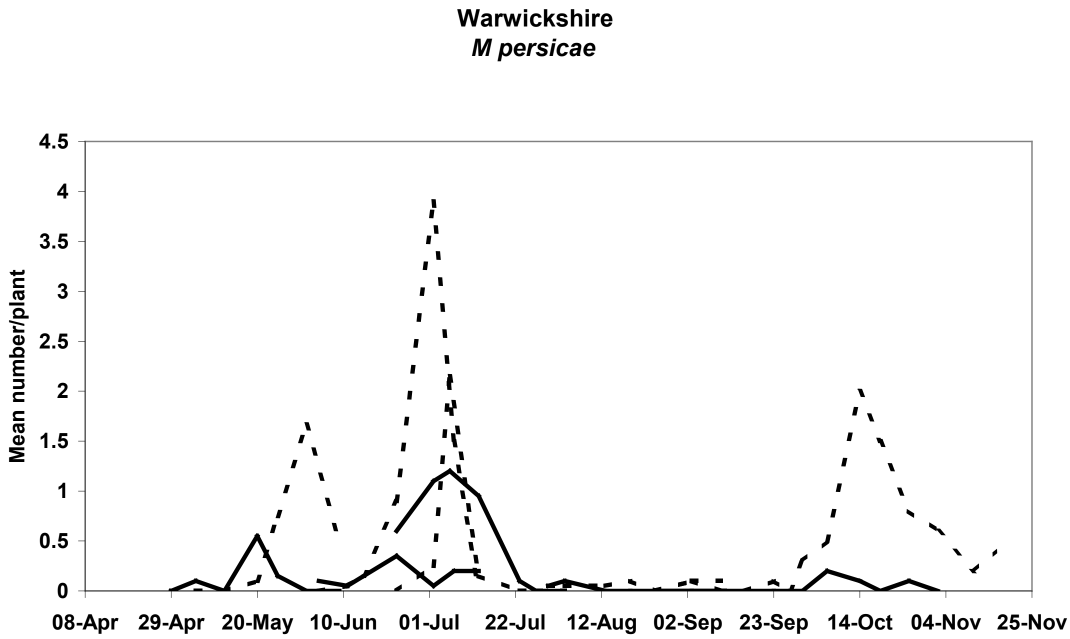

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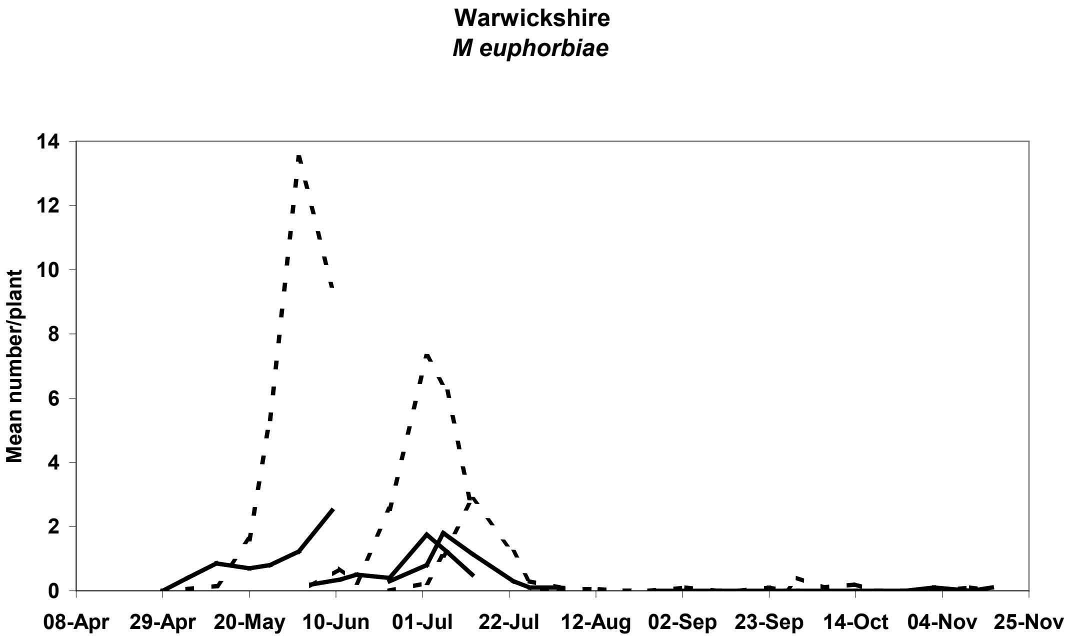

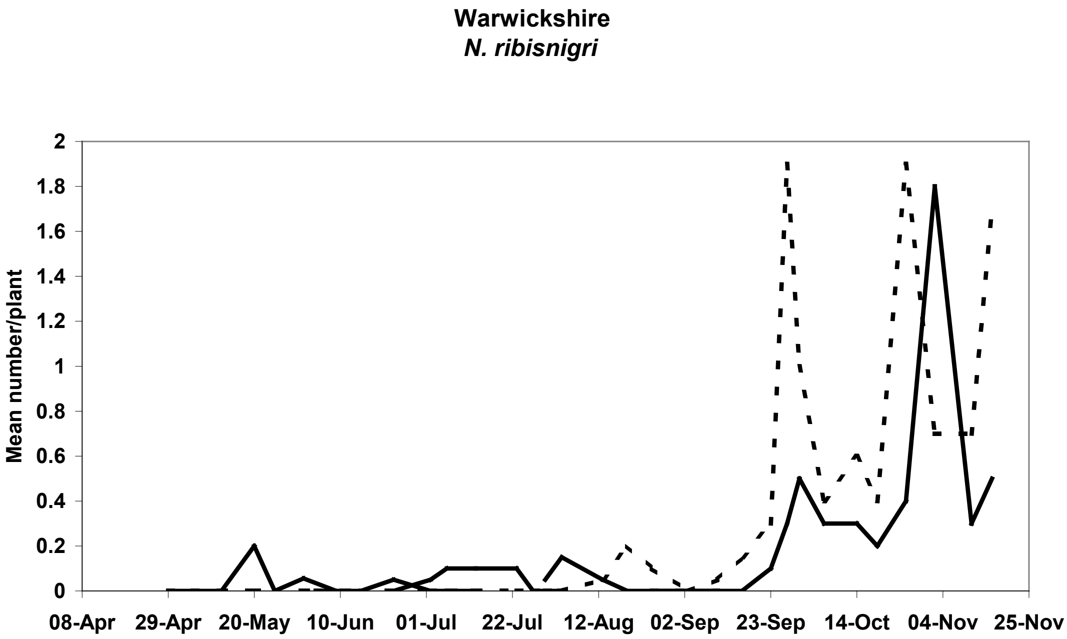

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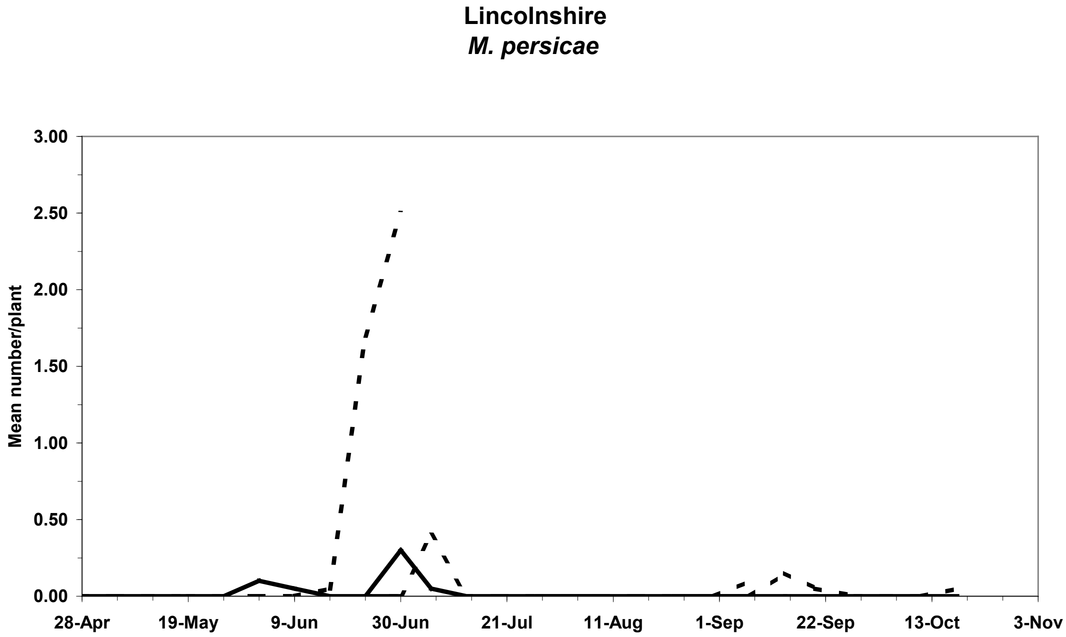

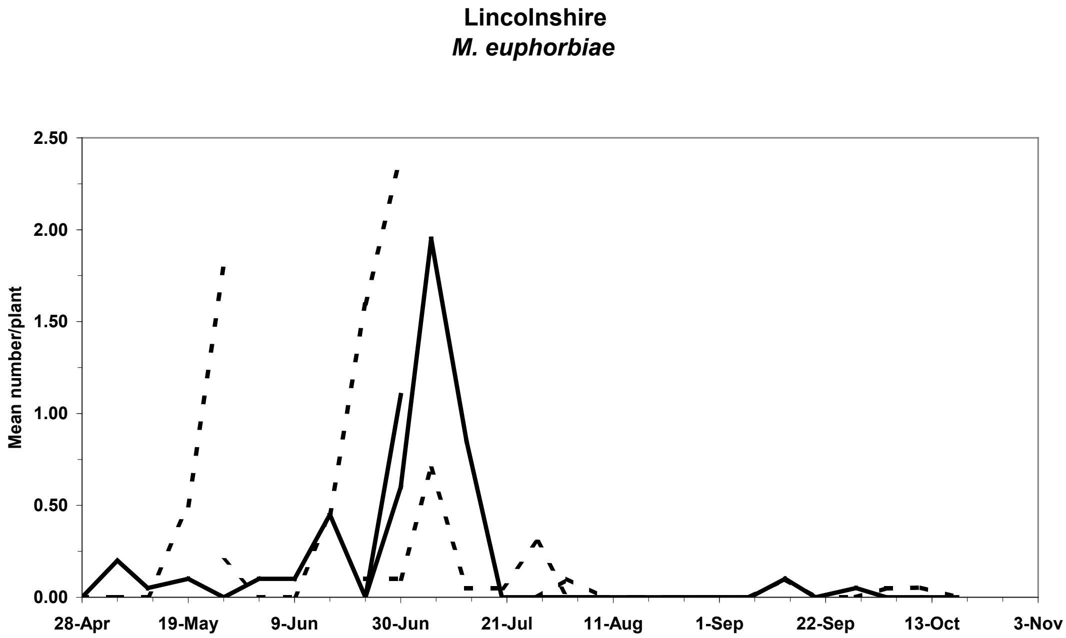

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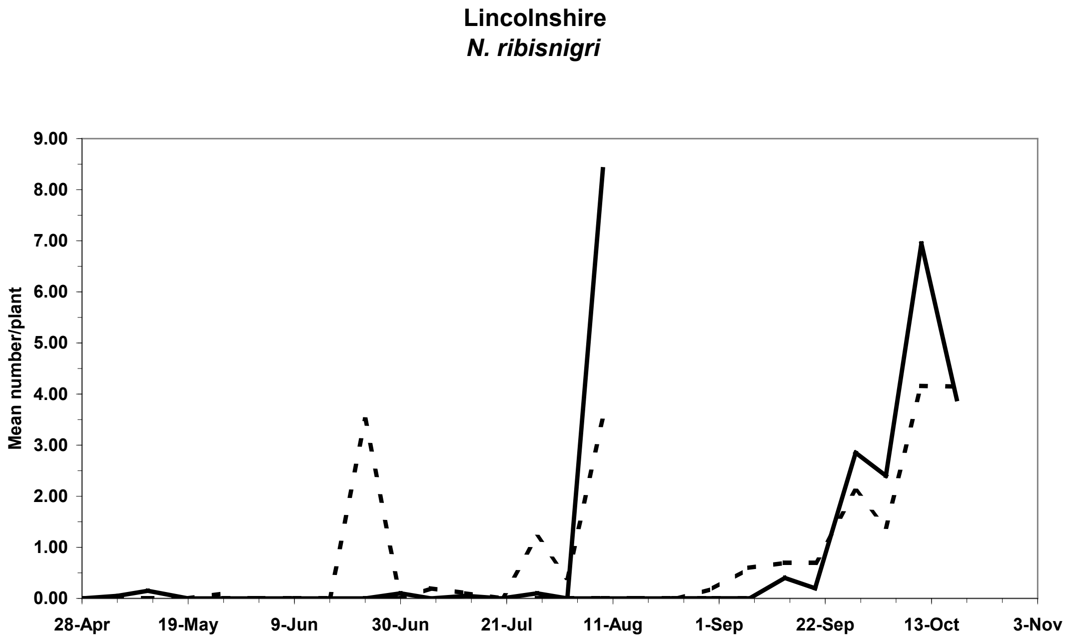

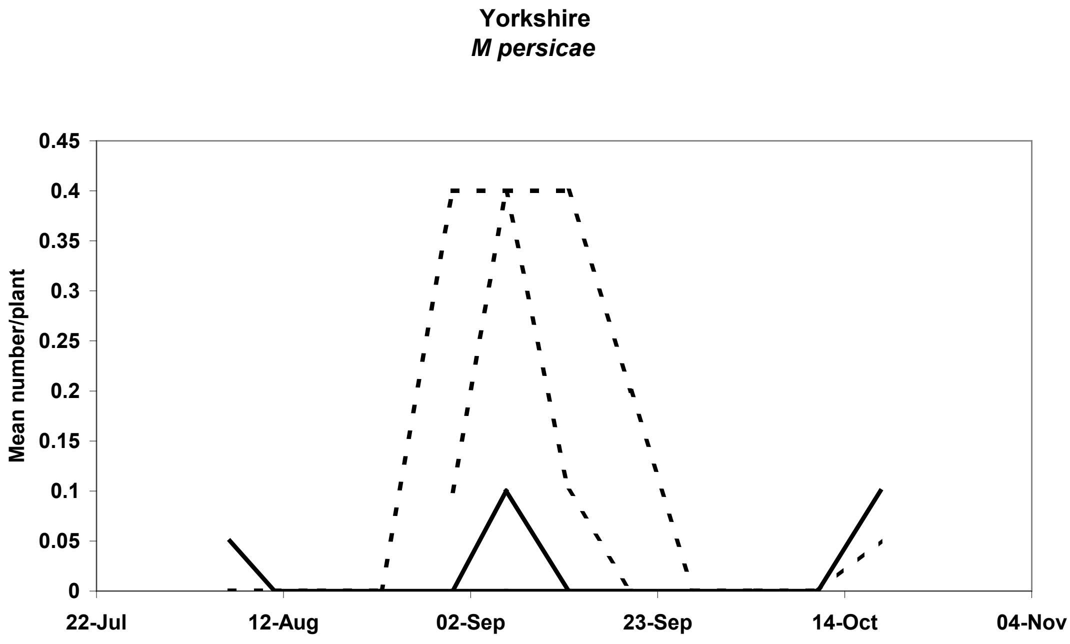

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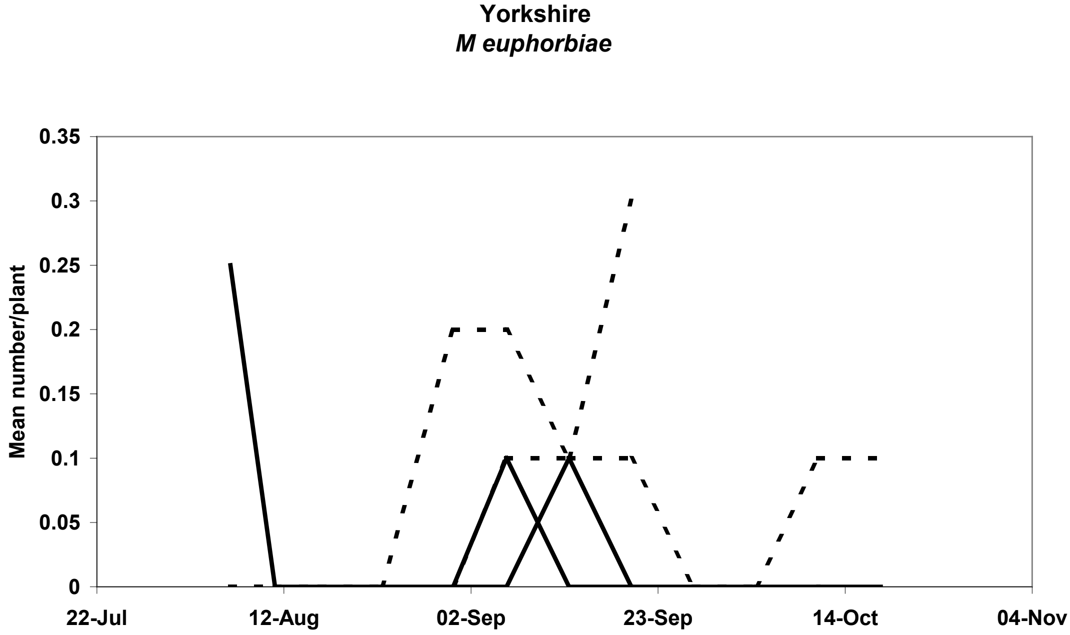


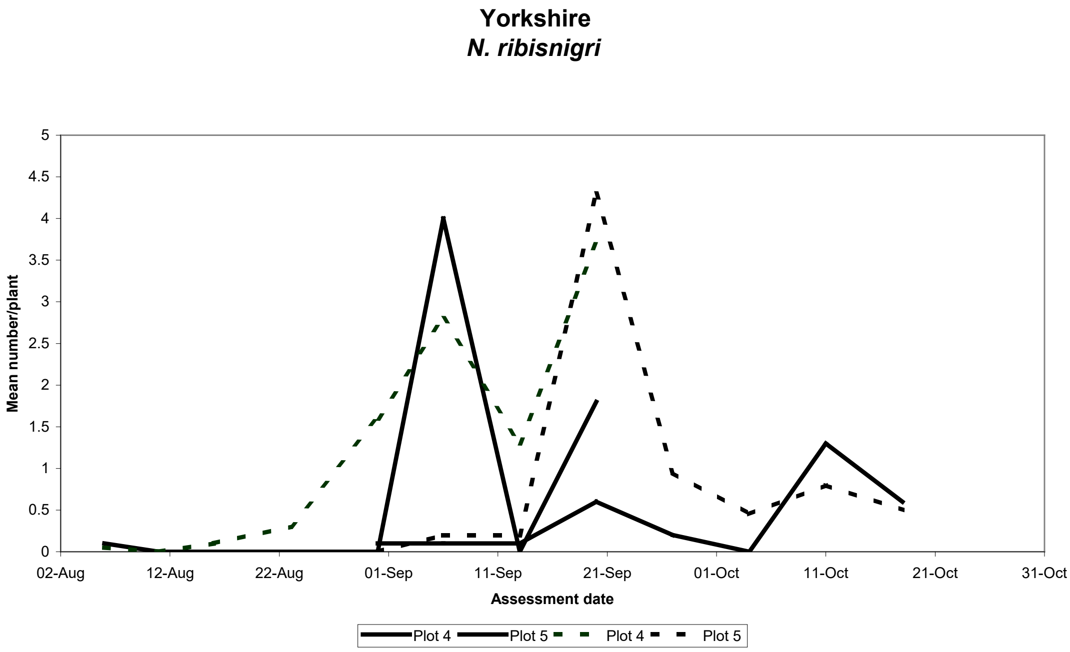
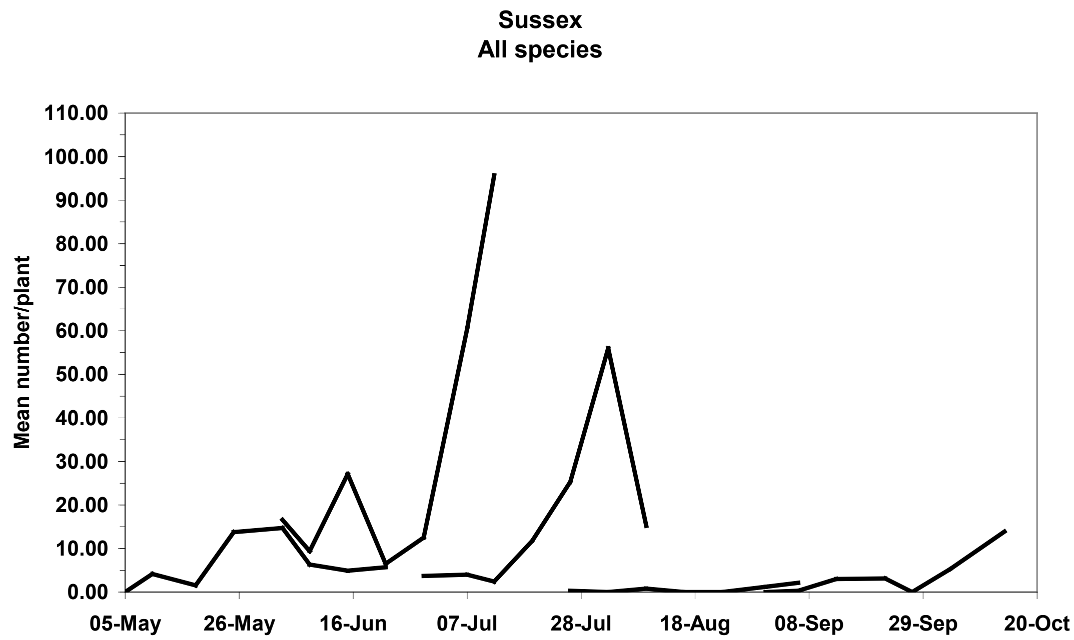
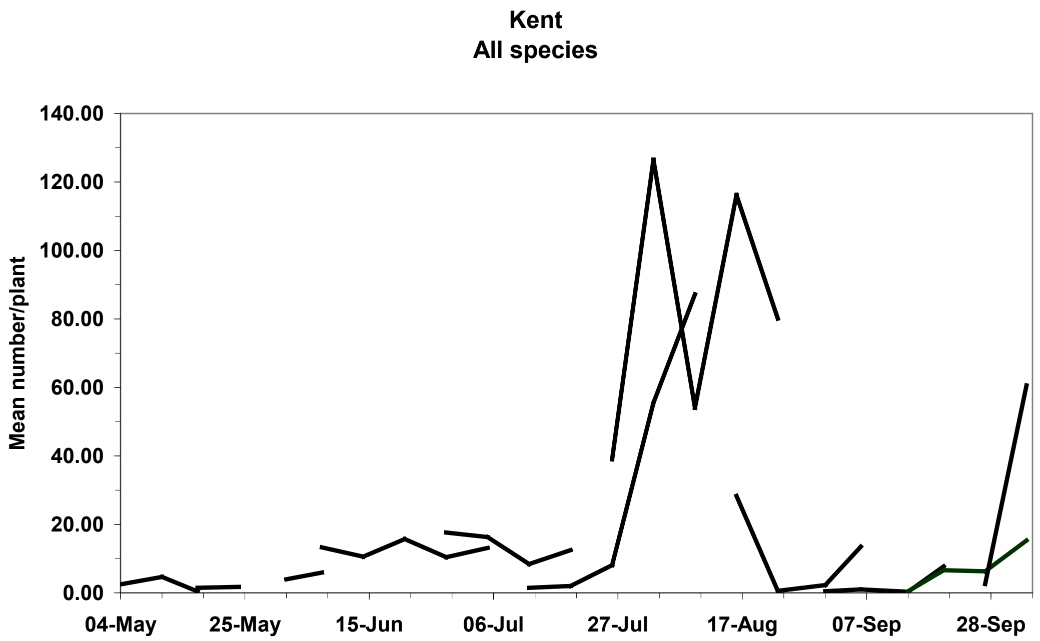


Figure 3. The numbers of aphids (all species) found on untreated lettuce plants in 1999.





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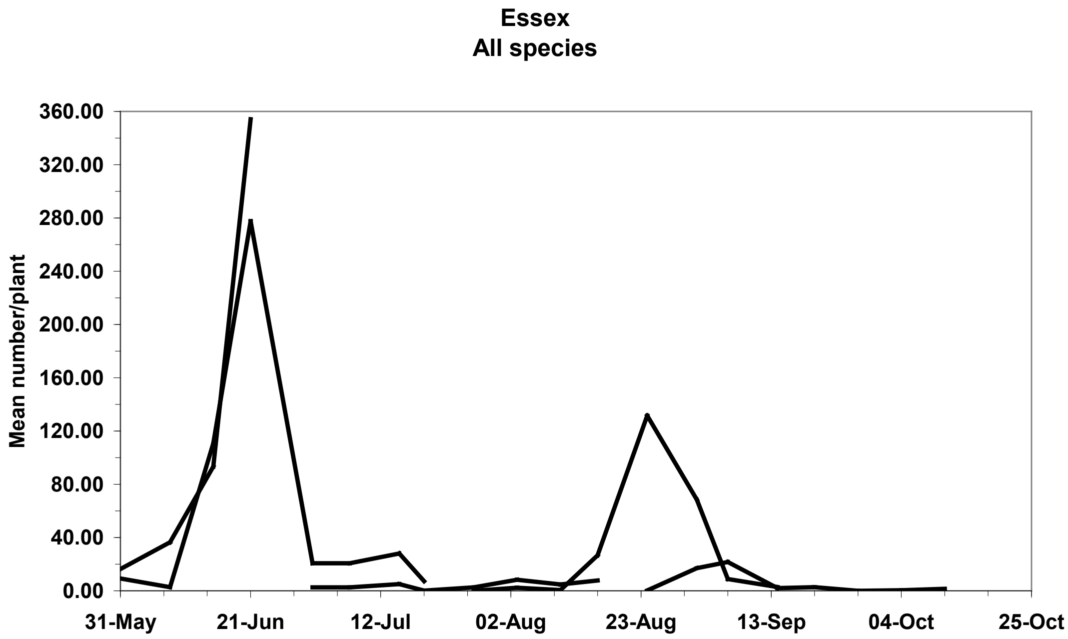

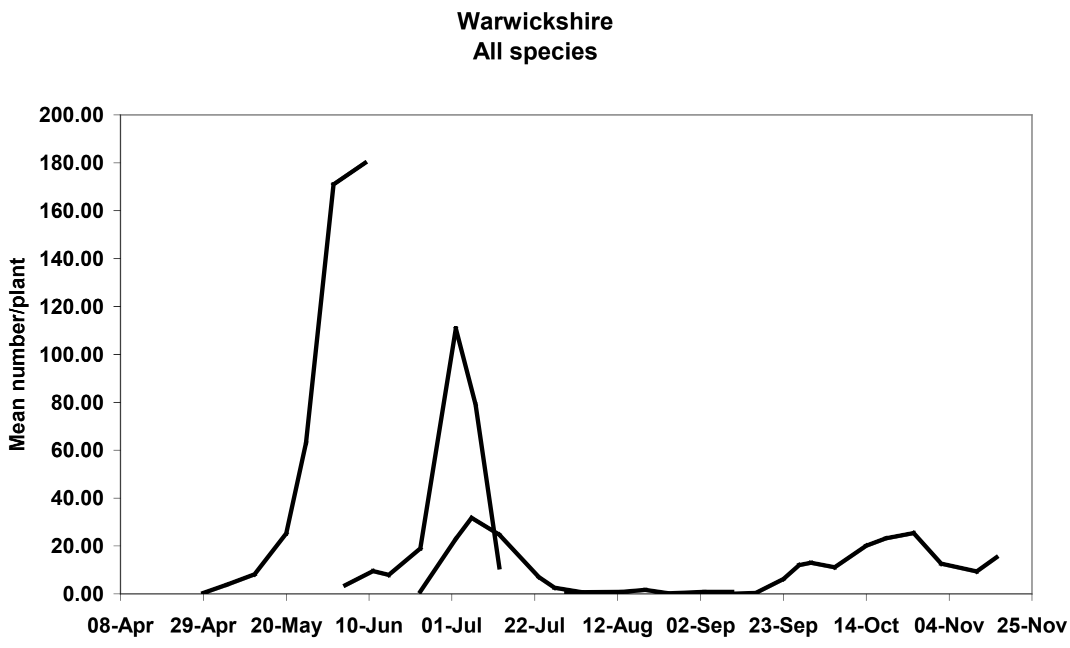

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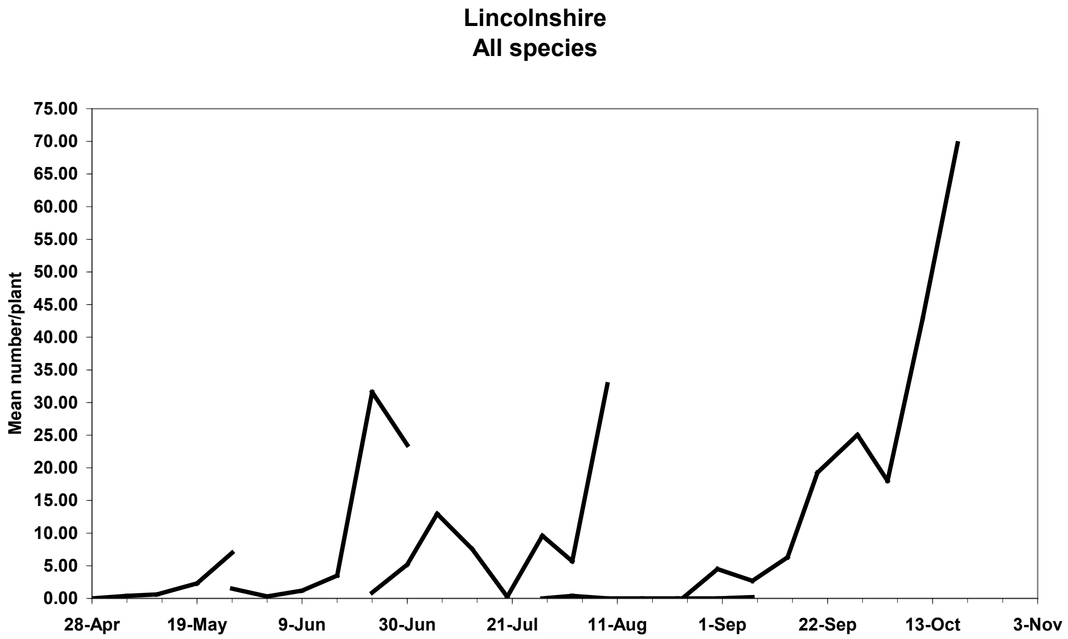


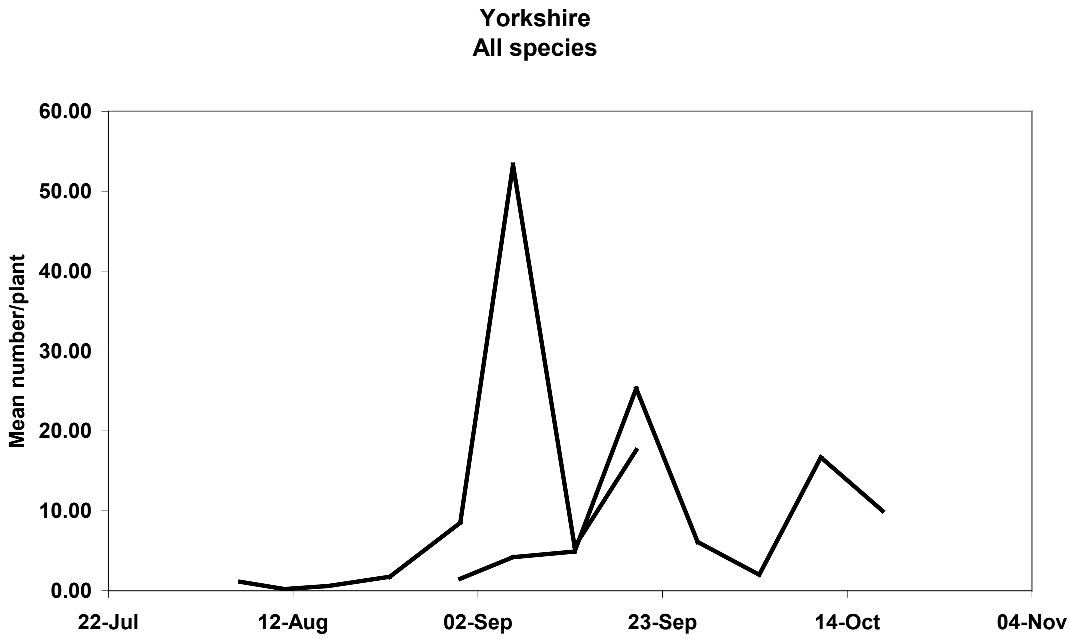


Figure 4. Relationship between timing of key infestation events and mean winter air temperature (*M. persicae*).

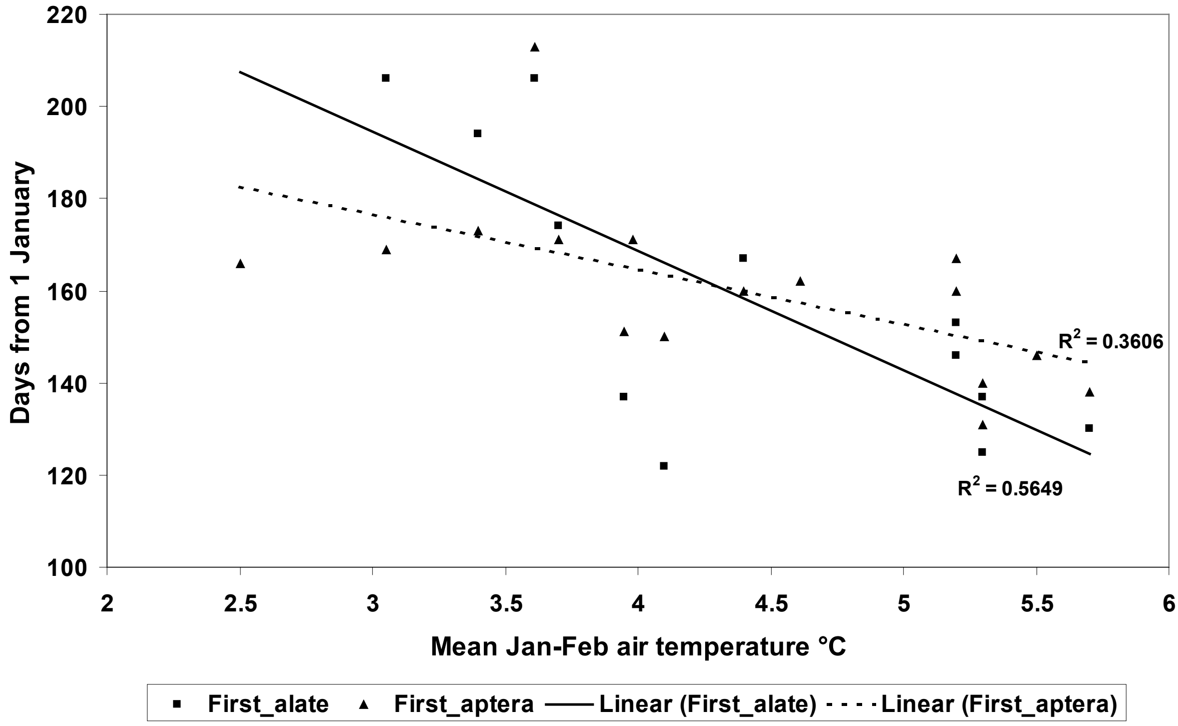


Figure 5. Relationship between timing of key infestation events and mean winter air temperature (*M. euphorbiae*).

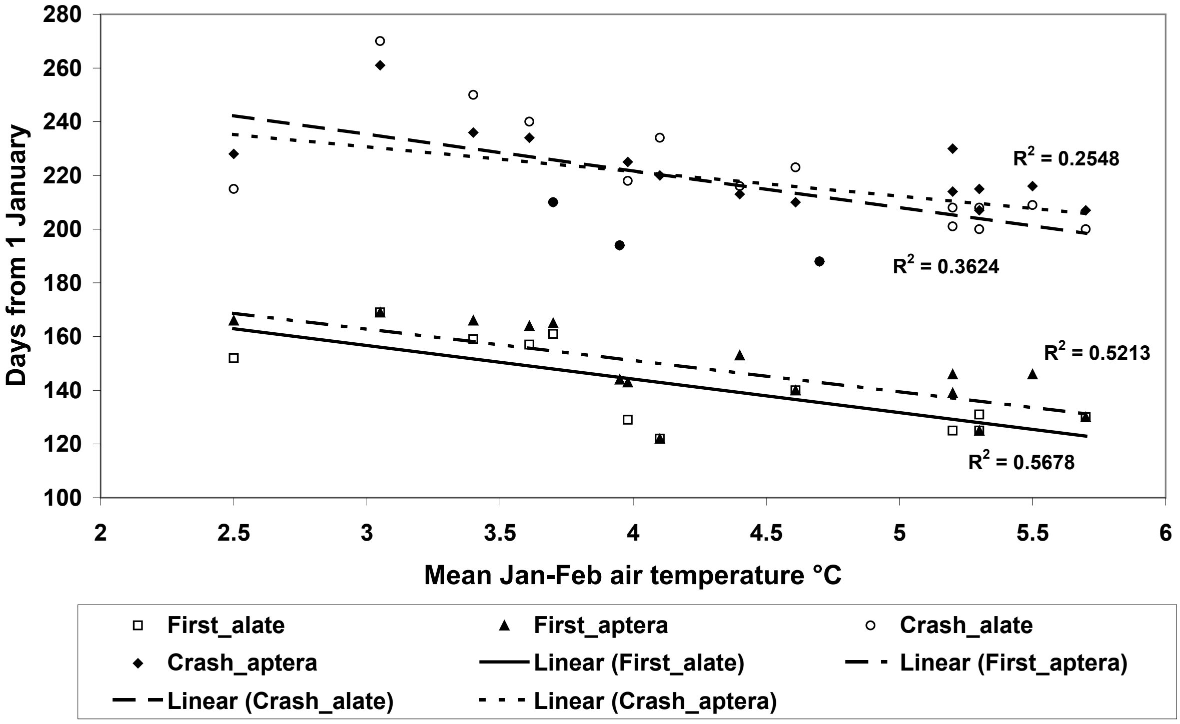
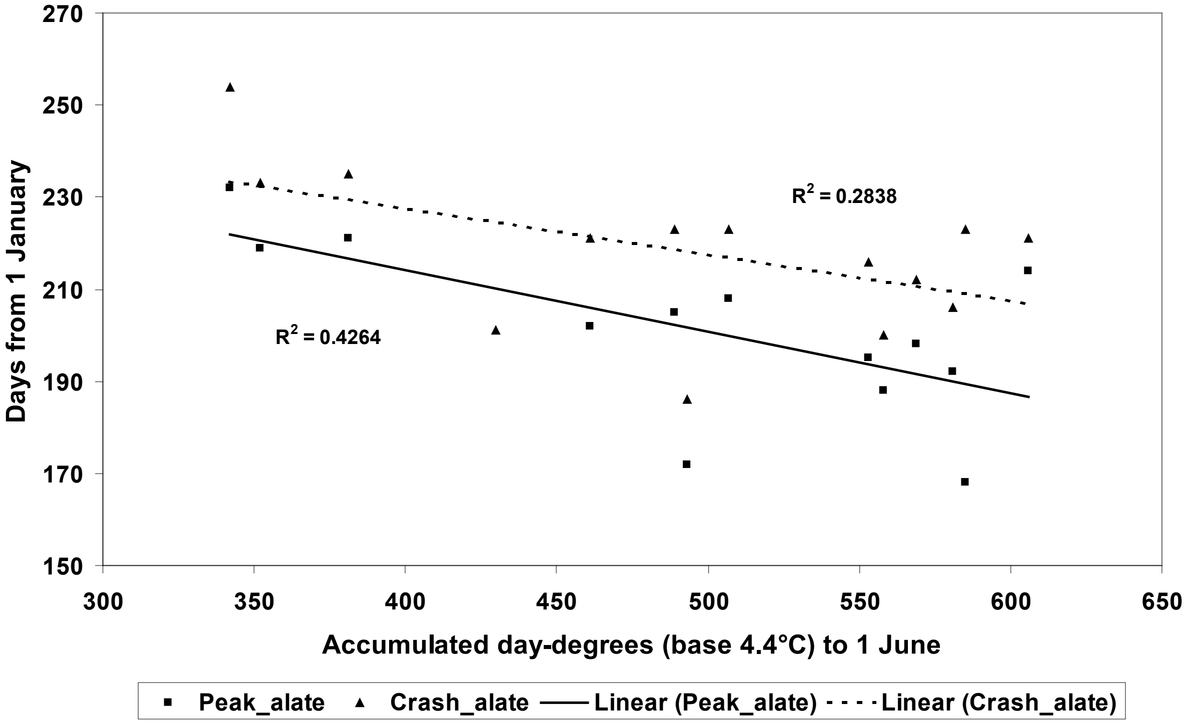


Figure 6. Relationship between timing of key infestation events and accumulated day-degrees (base 4.4ºC) from 1 February (*N. ribisnigri*).


270
250
230
210
190
170
150
Days from 1 January
300
350
400
450
500
550
600
650
Accumulated day-degrees (base 4.4°C) to 1 June
R2 = 0.2838
R2 = 0.4264
Peak_alate
Crash_alate
Linear (Peak_alate)
Linear (Crash_alate)

Appendix 1. Typical sampling plan for lettuce plots at monitoring sites.

HDC Lettuce Aphids 2000 - Plot/Sampling Plan

Plot size 4 rows x 70 plants

KEY

G = Guard plant
1 = Plants for first sample
etc.

NB

Samples are normally 10 plants except when only one plot is being sampled - the sample size then increases to 20 plants.

Plot 1

G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G
G 1 1 1 1 1 1 1 1 1 1 G 2 2 2 2 2 2 2 2 2 2 G 3 3 3 3 3 3 3 3 3 3 G 4 4 4 4 4 4 4 4 4 4 G 5 5 5 5 5 G 6 6 6 6 6 G 7 7 7 7 7 G 8 8 8 8 8 G
G 1 1 1 1 1 1 1 1 1 1 G 2 2 2 2 2 2 2 2 2 2 G 3 3 3 3 3 3 3 3 3 3 G 4 4 4 4 4 4 4 4 4 4 G 5 5 5 5 5 G 6 6 6 6 6 G 7 7 7 7 7 G 8 8 8 8 8 G
G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G

Plot 2

G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G
G 5 5 5 5 5 G 6 6 6 6 6 G 7 7 7 7 7 G 8 8 8 8 8 G 9 9 9 9 9 G 10 10 10 10 10 G 11 11 11 11 11 G 12 12 12 12 12 G G G G G G G G G G G G G G G G G G G G
G 5 5 5 5 5 G 6 6 6 6 6 G 7 7 7 7 7 G 8 8 8 8 8 G 9 9 9 9 9 G 10 10 10 10 10 G 11 11 11 11 11 G 12 12 12 12 12 G G G G G G G G G G G G G G G G G G G G
G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G

Plot 3

G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G
G 9 9 9 9 9 G 10 10 10 10 10 G 11 11 11 11 11 G 12 12 12 12 12 G 13 13 13 13 13 G 14 14 14 14 14 G 15 15 15 15 15 G 16 16 16 16 16 G G G G G G G G G G G G G G G G G G G G
G 9 9 9 9 9 G 10 10 10 10 10 G 11 11 11 11 11 G 12 12 12 12 12 G 13 13 13 13 13 G 14 14 14 14 14 G 15 15 15 15 15 G 16 16 16 16 16 G G G G G G G G G G G G G G G G G G G G
G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G

Plot 4

G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G
G 13 13 13 13 13 G 14 14 14 14 14 G 15 15 15 15 15 G 16 16 16 16 16 G 17 17 17 17 17 G 18 18 18 18 18 G 19 19 19 19 19 G 20 20 20 20 20 G G G G G G G G G G G G G G G G G G G G
G 13 13 13 13 13 G 14 14 14 14 14 G 15 15 15 15 15 G 16 16 16 16 16 G 17 17 17 17 17 G 18 18 18 18 18 G 19 19 19 19 19 G 20 20 20 20 20 G G G G G G G G G G G G G G G G G G G G
G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G

Plot 5

G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G
G 17 17 17 17 17 G 18 18 18 18 18 G 19 19 19 19 19 G 20 20 20 20 20 G 21 21 21 21 21 21 21 21 21 21 G 22 22 22 22 22 22 22 22 22 22 G 23 23 23 23 23 23 23 23 23 23 G 24 24 24 24 24 24 24 24 24 24 G
G 17 17 17 17 17 G 18 18 18 18 18 G 19 19 19 19 19 G 20 20 20 20 20 G 21 21 21 21 21 21 21 21 21 21 G 22 22 22 22 22 22 22 22 22 22 G 23 23 23 23 23 23 23 23 23 23 G 24 24 24 24 24 24 24 24 24 24 G
G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G G