HDC Project FV 163a

FINAL REPORT

Brassicas: Refinement and field validation of forecasts for the caterpillar pests of brassicas.

Rosemary Collier and Sally Minns

Horticulture Research International
Wellesbourne
Warwick CV35 9EF

June 2001

© 2001 Horticultural Development Council

Project Title:	Brassicas: Refinement and field validation of forecasts for the caterpillar pests of brassicas
Project Number:	FV 163a
Project Leader:	Rosemary Collier
Final Report:	1999-2001
Previous Reports and dates:	Annual Report, June 2000
Key workers and roles:	Rosemary Collier, project leader Sally Minns, crop monitoring, data collation and summary Jennie Blood Smyth and colleagues, crop monitoring
Location of Project:	HRI Wellesbourne, HRI Kirton, commercial crops
Project Co-ordinator:	Mr P Effingham, Marshall Bros (Butterwick Ltd), The Mill, Butterwick, Boston, Lincs PE22 0JQ Mr J Kelley, Bedfordshire Growers, Potton Road, Biggleswade, Beds SG18 0ER
Date project commenced:	1 May 1999
Date project completed:	30 April 2001
Key words:	Brassicas, forecasts, caterpillars, diamond-back moth, small white butterfly, cabbage moth, garden pebble moth, silver Y moth, large white butterfly, traps, monitoring

Whilst reports issued under the auspices of the HDC are prepared from the best available information, neither the authors nor the HDC can accept any responsibility for inaccuracy or liability for loss, damage or injury from the application of any concept or procedure discussed.

©2001 Horticultural Development Council
The contents of this publication are strictly private to HDC members. No part of this publication may be reproduced in any form or by any means without prior written permission of the Horticultural Development Council.

CONTENTS OF REPORT

Page

PRACTICAL SECTION FOR GROWERS

COMMERCIAL BENEFITS OF THE PROJECT 1

BACKGROUND AND OBJECTIVES 1

SUMMARY OF RESULTS AND CONCLUSIONS 1

ACTION POINTS FOR GROWERS 2

ANTICIPATED PRACTICAL AND FINANCIAL BENEFITS 3

SCIENCE SECTION

INTRODUCTION 5

EXPERIMENTAL 6

DISCUSSION 19

CONCLUSIONS 21

TECHNOLOGY TRANSFER 25

ACKNOWLEDGEMENTS 25

REFERENCES 25

APPENDIX 27

© 2001 Horticultural Development Council

PRACTICAL SECTION FOR GROWERS

COMMERCIAL BENEFITS OF THE PROJECT

This project has refined and validated forecasts of the timing of activity of the key caterpillar pests of brassica crops and provided guidelines on how the development of infestations of each species of pest caterpillar should be monitored. The project will help brassica growers to anticipate periods of caterpillar infestation. This should lead to better use of crop monitoring resources and improved targeting of insecticide treatments.

BACKGROUND AND OBJECTIVES

The caterpillars of several species of butterfly and moth can damage brassica crops. However, attacks by caterpillars are sporadic and do not occur in every crop each year. Considerable savings can be made in applications of insecticides for caterpillar control by applying sprays only when there are sufficient insects in the crop to warrant treatment. The purpose of this project is to refine and validate forecasts of the timing of activity of the caterpillar pests of brassica crops so that crop walking and subsequent spray applications can be targeted more accurately.

SUMMARY OF RESULTS AND CONCLUSIONS

Forecasts of the development of the pest caterpillars of brassica crops (diamond-back moth, small white butterfly, cabbage moth, garden pebble moth), which were developed originally in FORTRAN in LINK Project FV 163, were reprogrammed for use in the MORPH decision-support software.

The pest caterpillars of brassica crops were monitored at 8 sites in 1999 and 6 sites in 2000. Pheromone traps were used to monitor adult moths and water traps to monitor butterflies. The numbers of each of the immature stages (eggs, caterpillars, pupae) were counted on plants in insecticide-free plots of Brussels sprouts. Very few insects were found at any of the sites in 1999; numbers were higher in 2000. The new versions of the forecasts were validated using these data, and additional data collected during 1996-98 as part of the HRI Kirton pest monitoring service.

Because the diamond-back moth is a migrant species, pheromone traps are the most effective way of determining when infestations will occur, and the current diamond-back moth model uses moth counts to trigger a forecast of subsequent population development. For the purposes of forecast validation, moth counts from the first migration were used to predict the timing of the subsequent generations. In general, when used in this way, the diamond-back moth forecast gave a good description of the timing of subsequent periods of activity. This is not necessarily the way that this forecast would be used in practice, since it is likely that moth captures would be updated on a weekly, or more frequent basis,

© 2001 Horticultural Development Council

and the model would be used to predict when caterpillars would be likely to occur. The forecasts for the small white butterfly and garden pebble moth gave a good indication of the periods when caterpillars were likely to be found in brassica crops. It was less easy to validate the cabbage moth forecast, because caterpillar numbers were so low.

This study also confirms observations made in Project FV 163, that female diamond-back moths are laying eggs at the time that male moths are captured in pheromone traps. Similarly, pheromone trap catches of the silver Y moth could be used to trigger a forecast to indicate when caterpillars of this pest might be expected. This might be of more value to salad growers than brassica growers.

The data from all insecticide-free Brussels sprout plots monitored for caterpillar pests in Projects FV 163 (1995-97), FV 163a (1999-2000) and as part of the HRI Pest Monitoring Service (1996-2000) were collated. The numbers of adults trapped and eggs, caterpillars and pupae found/plant on each sampling occasion were calculated for each of the 39 sets of data.

Preliminary analyses were made to determine the relationship between the numbers of adults captured in traps, the numbers of eggs found on plants (where sampling was feasible) and the numbers of caterpillars infesting insecticide-free Brussels sprout plants in the monitoring plots. The monitoring data were summarised by separating the periods of moth and caterpillar activity into 'generations'. The peak numbers of moths captured/trap/day and the peak numbers of caterpillars found/plant in each generation were determined and compared. In some cases, adult trapping data could be used to provide information on both the timing and likely severity of infestations, whilst in others, adult trapping was less reliable.

ACTION POINTS FOR GROWERS

- The data collected in 1999-2000 confirm that the diamond-back moth and small white butterfly are the most widespread caterpillar pests of brassicas in the UK. The silver Y moth was common also. The cabbage moth and garden pebble moth are localised pests.
- Caterpillar infestations were slight in 1999 and there were no instances where more than one caterpillar of each species/plant was found. This implies that few insecticide treatments would have been required for caterpillar control. This was supported by the results of supervised control experiments at HRI Kirton (FV 194), where few sprays were applied to control caterpillars and even the insecticide-free control plot suffered very slight damage.
- Diamond-back moth caterpillars were present in crops from late June until early November. This is a migrant species and the timing of immigration varies from year to

© 2001 Horticultural Development Council

year. Pheromone traps should be used to indicate when large numbers of moths are entering crops since female diamond-back moths will lay eggs at the same time that the traps are capturing male moths. Diamond-back moth development is rapid. The forecast, which is triggered by moth trap captures, can be used to predict when caterpillars will be found and when the next generation is likely to occur. The relationship between the numbers of moths captured in pheromone traps and the numbers of caterpillars found subsequently on plants in insecticide-free plots was not particularly consistent.

- Most of the small white butterfly caterpillars found on plants were the progeny of either the second or third generations, confirming that the first generation is the least important. There appears to be a fairly consistent relationship between the numbers of eggs found on plants and the numbers of caterpillars found subsequently, so egg sampling could give an indication of subsequent caterpillar numbers. The small white butterfly forecast can be used to indicate the periods when eggs are being laid and when caterpillars are likely to be found.
- Silver Y moths were captured at all sites. They are also migrant moths and the timing of immigration varies from year to year. Previous studies suggested that their caterpillars were not important pests of brassicas. Determination of the relationship between the numbers of moths trapped and the numbers of caterpillars found subsequently on plants supports this.
- Both the cabbage moth and garden pebble moth are localised pests. If crops in the locality have been infested previously, the risk of attack is likely to be increased. Pheromone traps for the cabbage moth appear to be relatively non-specific and ineffective, whereas those for the garden pebble moth are specific and appear to give a good indication of the likelihood of infestation by caterpillars. The forecasts for both pests can be used to indicate the periods when egg laying is likely to occur and when caterpillars can be found. The cabbage moth model has been the most difficult to validate reliably as infestations have been so small.
- The large white butterfly does not appear to be important commercially.

ANTICIPATED PRACTICAL AND FINANCIAL BENEFITS

Leafy brassicas are worth about £160M annually (MAFF Basic Horticultural Statistics for the UK, 1989/90-1999/00) and cover an area of 35,000 ha. In 1995 (Garthwaite *et al.*, 1995) a total area of 250,000 ha was treated with insecticides, of which about 40% (100,000 ha) were for caterpillar control. The presence of caterpillars or caterpillar damage in produce can lead to supermarket rejections.

MAFF and HDC-funded work has shown that a 25% reduction in the number of sprays applied for caterpillar control might well be feasible. Sprays to brassica crops cost about £200/ha (Nix, 1998) and approximately 25% of these will be for caterpillar control (about

© 2001 Horticultural Development Council

£50/ha). Thus even a 5% reduction in the number of treatments applied for caterpillar control to the 35,000 ha brassicas grown in the UK could be worth about £90,000 per year, depending on the costs of insecticide and treatment. This would give a cost-benefit relationship of 1:10 for a period of five years.

Other benefits would accrue from a reduction in insecticide use, which would be favoured highly by consumers. For example, a reduction in the number of pyrethroid sprays applied to crops would benefit non-target species and reduce the rate of development of insecticide resistance in other pests. Perceived benefits are that:

- The project will increase brassica growers' knowledge of caterpillar life cycles and help them anticipate periods of caterpillar infestation. This should lead to better use of crop monitoring resources and improved targeting of insecticide treatments.
- The project will provide the industry with validated forecasts of the timing of caterpillar 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.
- 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. The pyrethroids used for caterpillar control are broad-spectrum insecticides, which may kill a wide range of non-target species, whilst more specific insecticides such as *Bacillus thuringiensis* are relatively expensive.
- Reduction in the use of pyrethroid sprays for caterpillar control may reduce the rate of development of insecticide resistance in other pests such as the peach-potato aphid (*Myzus persicae*).

© 2001 Horticultural Development Council

SCIENCE SECTION

INTRODUCTION

Edible brassica crops are sprayed extensively to control foliar pests, particularly caterpillars and aphids (Garthwaite *et al.*, 1995). Crops may be treated routinely with little reference to pest numbers or crop growth stage. The caterpillars of several species of butterfly and moth can damage brassica crops. However, extensive field sampling during LINK project FV 163 has shown that attacks by caterpillars are sporadic and do not occur in every crop each year.

Previous MAFF-funded research (FO5D, PI0321), and a parallel HDC-funded project (FV 119), have shown that considerable savings can be made in applications of insecticides for caterpillar control by applying sprays only when there are sufficient insects in the crop to warrant treatment. This was done using systems of supervised control to apply sprays only when necessary (Blood Smyth *et al.*, 1992; 1994; Emmett, 1992; Paterson *et al.*, 1994). Pest numbers were assessed by field sampling, and treatment decisions were made using pest tolerance levels (thresholds). However, there was still a need to develop sampling techniques further to make them more appropriate to commercial practice and to reduce the costs of monitoring. One of the main objectives of LINK Project FV 163 was to develop and validate forecasts that predict the timing of key events in the development of caterpillar pests of brassicas, so that crop monitoring can be targeted more accurately.

Of the six species of caterpillar studied in the LINK project, the diamond-back moth (*Plutella xylostella*) was the most damaging commercially. This was followed by, in decreasing order of importance, the small white butterfly (*Pieris rapae*), cabbage moth (*Mamestra brassicae*), garden pebble moth (*Evergestis forficalis*), large white butterfly (*Pieris brassicae*) and silver Y moth (*Autographa gamma*). Preliminary forecasts of the timing of activity were developed for the diamond-back moth, small white butterfly, cabbage moth and garden pebble moth. These were validated using monitoring data collected at four sites during 1994-1997. The forecasts now require validation over the geographical range of brassica production in the UK, and further refinement, before they can be used on a commercial scale. The purpose of this project is to refine and validate forecasts of the timing of activity of the caterpillar pests of brassica crops so that these can be made available to growers, thus taking LINK project FV 163 into the field phase.

Apart from caterpillars, a range of fly, beetle and aphid pests attacks brassica crops. Forecasts have been developed for the cabbage root fly (*Delia radicum*) and pollen beetle (*Meligethes* spp.) (FV 13a, FV 44, FV 127) and predictions using Meteorological Office weather data are available currently to growers as a fax and e-mail service from HRI Wellesbourne. These forecasts have also been incorporated into the MORPH decision

© 2001 Horticultural Development Council

support software and have been available to growers for use with their own weather data since 1999.

EXPERIMENTAL

Objective 1. Obtain field-monitoring data for diamond-back moth, small white butterfly, cabbage moth and garden pebble moth from geographically separate areas of brassica production.

1.1 Locate monitoring sites in commercial crops in Devon/Cornwall, Kent, Lancashire, Bedfordshire (3 sites in each year). The aim is to obtain information from regions which are geographically separate from those used to develop the forecasts in FV 163. It should also be possible to use the less detailed information obtained for the HRI Kirton Pest Monitoring Service to validate the forecasts in South Lincolnshire, by combining information from all five monitoring sites. (ADAS, HRI)

The monitoring plots funded by this project (managed by ADAS) were located on commercial farms in Devon, Kent and Lancashire. The HRI Pest Monitoring Service provided data from five sites in Lincolnshire in 1999 and three sites in 2000 (in commercial crops and at HRI Kirton).

	Year	County	Location	Origin of data
1	1999	Devon	Moreleigh	Current project
2		Kent	Canterbury	"
3		Lancashire	Lathom	"
4		Lincolnshire	HRI Kirton	Data provided by HRI Pest
5			Butterwick	Monitoring Service
6			Wainfleet	"
7			Donington	"
8			Moulton	"
9	2000	Devon	Stockleigh Pomeroy	Current project
10		Kent	Canterbury	"
11		Lancashire	Ormskirk	"
12		Lincolnshire	HRI Kirton	Data provided by HRI Pest
13			Butterwick	Monitoring Service
14			Holbeach	"

© 2001 Horticultural Development Council

1.2 Set up plots of Brussels sprouts (minimum 400 plants) to monitor caterpillar pests. The plots should be insecticide-free. (ADAS, HRI)

Insecticide-free monitoring plots were established at all the sites in both years.

1.3 Set up pheromone traps and water traps to monitor adult moths and butterflies at each site. (ADAS, HRI)

Pheromone traps to monitor diamond-back moth, cabbage moth, garden pebble moth and silver Y moth were set up at each of the sites. Yellow water traps were used to monitor small and large white butterflies.

1.4 Each week from May to October, identify and count all eggs, caterpillars and pupae (where appropriate) of each species of caterpillar pest on 100 plants at each site. Service pheromone and water traps and record numbers of adults of each species captured. (ADAS, HRI)

Pest numbers were recorded each week.

Objective 2. Refine and validate forecasts for diamond-back moth, small white butterfly, cabbage moth and garden pebble moth.

2.1 Refine forecasts of the timing of caterpillar attacks. (HRI)

The caterpillar forecasts, which were developed originally in FORTRAN, were re-programmed for use in the MORPH decision-support software.

2.2 Collate monitoring data for each species. (HRI)

Data for each of the species sampled in 1999 and 2000 were tabulated and summarised graphically (*Appendices 1-10*). In 1999, numbers of all species, apart from the silver Y moth, were low at all sites.

Diamond-back moth

1999 (Appendix 1)

No moths or caterpillars were found at the monitoring site in Devon. Very few moths were captured at the site in Kent and no caterpillars were found. Moths and caterpillars were found at all other sites, and their numbers were greatest at Butterwick in Lincolnshire. However, there was never more than one caterpillar/plant. Caterpillars were present from July until September.

2000 (Appendix 2)

Moths and caterpillars were found at all of the monitoring sites. Peak numbers of moths were captured in late June (Devon), late July (Kent and Lancashire) and August (Lincolnshire). Moth numbers were greatest in Lincolnshire (18 moths/trap/day at peak) and lowest in Devon (2 moths/trap/day at peak). Peak numbers of caterpillars were found

© 2001 Horticultural Development Council

in late June – early July (Devon, Kent, Lancashire) and mid-August (Lincolnshire). Numbers of caterpillars were greatest in Lincolnshire (34/plant at peak) and least in Devon (1/plant at peak). Sampling started late in Devon and Kent and it is likely that the first moth migration was missed in Kent at least.

Small white butterfly

1999 (Appendix 3)

Eggs, caterpillars and/or butterflies were found at most sites, although in very small numbers. The largest numbers of butterflies and caterpillars were found during August and September.

2000 (Appendix 4)

Eggs, caterpillars and/or butterflies were found at most sites, in lower numbers than the diamond-back moth. The largest numbers of butterflies, eggs and caterpillars were found during August and September.

Cabbage moth

1999 (Appendix 5)

Very low numbers of cabbage moth adults and caterpillars were found at two sites, in Kent and at Kirton. Few were found elsewhere.

2000 (Appendix 6)

No cabbage moths were found in Devon or at Butterwick. Low numbers were found elsewhere, mainly during August and September.

Garden pebble moth

1999 (Appendix 7)

Again, low numbers of garden pebble moths were found at two sites only (in Kent and Lincolnshire). Most caterpillars were found during September.

2000 (Appendix 8)

Garden pebble moths were found at all sites apart from Ormskirk in Lancashire. Caterpillars were found during August – October.

Silver Y moth

1999 (Appendix 9)

The silver Y moth was the most numerous lepidopterous pest at all sites. The largest numbers of moths were captured in mid-late July and the largest numbers of caterpillars were often found soon afterwards. Although moth numbers were relatively high, there was never more than one caterpillar/plant.

2000 (Appendix 10)

© 2001 Horticultural Development Council

Silver Y moths were found at all sites. The largest numbers of moths were captured during mid-June to mid-July and the largest numbers of caterpillars were often found soon afterwards. There was never more than one caterpillar/plant.

Large white butterfly

Large white butterfly caterpillars were found only occasionally. Their habit of laying their eggs in batches, so that the caterpillars, which hatch subsequently, feed in groups, means that small numbers of plants are infested and those that are, are extremely conspicuous.

2.3 Identify the start and end of each period of infestation for each species at each site. (HRI)

The periods during which caterpillars were found at each site in 1999 and 2000 are shown in **Table 1**. Diamond-back moth caterpillars were present in crops from late May until early November. This is a migrant species and the timing of immigration can vary considerably from year to year.

Most of the small white butterfly caterpillars were found during August-September and were the progeny of either the second or third generations. This confirms that the first generation is usually unimportant.

Silver Y moths were found at all sites. Caterpillars were found generally from late June through to October. This is another migrant species and once again, the timing of immigration can vary considerably from year to year.

Cabbage moths and garden pebble moths were the least common species and were not found at every site. Although garden pebble moth numbers were low (*Appendices 7-8*), most of the data collected showed clearly that there were two generations each year (e.g. data for Lincolnshire (all sites) in 2000). The separation of cabbage moth activity into two generations was less clear (*Appendices 5-6*).

© 2001 Horticultural Development Council

Table 1. The periods during which caterpillars of each species were found on plants in 1999 and 2000.

	Diamond-back moth	Small white butterfly	Cabbage moth	Garden pebble moth	Silver Y moth
1999					
Devon	None	11 Aug-8 Sep	None	None	30 Jun-8 Sep
Kent	None	16 Jul-4Oct	6 Sep-4 Oct	21 Sep-4 Oct	8 Jul-21 Sep
Lancashire	2 Jul–3 Sep	6 Aug-21 Sep	None	None	16 Jul-3 Sep
Lincolnshire					
Kirton	7 Jul–21 Oct	19 Aug-7 Oct	15 Jul-19 Aug	None	7 Jul-23 Sep
Butterwick	24 Jun–22 Sep	4 Aug-29 Sep	None	None	7 Jul-3 Nov
Donington	24 Jun–14 Oct	None	None	9-16 Sep	22 Jul-5 Aug
Moulton	24 Jun–7 Oct	4-11 Aug	None	None	1 Jul-23 Sep
Wainfleet	14 Jul–13 Oct	28 Jul – 13 Oct	None	None	14 Jul-25 Aug
2000					
Devon	4 Jul-8 Aug	25 Jul-5 Sep	None	25 Jul-15 Aug	4 Jul-5 Sep
Kent	16 Jun-8 Sep	16 Jun-9 Oct	7 Jul-9 Oct	None	30 Jun-8 Sep
Lancashire	21 Jun-7 Sep	9Aug-7 Sep	24 Aug-31 Aug	None	29 Jun-17 Aug
Lincolnshire					
Kirton	24 May-12 Oct	22 Jun-21 Sep	22 Jun-18 Oct	None	22 Jun -18 Oct
Butterwick	22 Jun-18 Oct	None	None	6 Jul-28 Sep	03-Aug
Holbeach	29 Jun-2 Nov	29 Jun-18 Oct	23 Aug-28 Sep	29 Jun-2 Oct	27 Jul-5 Oct

2.4 Validate caterpillar forecasts. (HRI)

Diamond-back moth

The diamond-back moth forecast was run for 11 site x year combinations (Kirton, Holbeach 1996-1998, Devon, Kent, Lancashire, Kirton, Holbeach 2000). Diamond-back moth numbers were too low in 1999 to compare them with forecasts. Weather data from meteorological stations at Chivenor (Devon), Charing (Kent), Crosby (Lancashire), Holbeach and Kirton (Lincolnshire) were used.

Because the diamond-back moth is a migrant species, and it is impossible to predict when the first moths will arrive, the model is triggered by pheromone trap captures. The numbers of moths captured must be entered into a file, which is used to run the program. Data on moth numbers can be added continually throughout the summer period or the model can be run using data recorded over periods of one or more weeks. The model uses this information to predict subsequent development of diamond-back moth populations throughout the summer and it can be used to indicate the timing of any stage (e.g. when caterpillars will hatch from eggs or when the next generation of moths will lay their eggs).

© 2001 Horticultural Development Council

For the purposes of this validation the numbers of moths captured during the first 'migration' only (usually a period of 3-5 weeks) have been used to produce forecasts of egg hatch for this first 'generation' and for subsequent generations. These forecasts have been compared graphically with the numbers of caterpillars found on insecticide-free Brussels sprout plants throughout the summer period (*Appendix 11*). In general, the forecasts based on the first migration give a good description of the pattern of population development during the rest of the summer. However, there are several reasons why the description might not be accurate over such a long period of time:

- Further migrations of moths may occur during the summer, which could change the overall pattern of activity
- Selective mortality may change the overall pattern of activity. For example, diamond-back moth mortality due to parasitism can be relatively high at certain times (LINK Project FV 163) and observations indicate that diamond-back moth numbers generally decline between generations so that the third generation is usually very small.
- The forecasts are for egg hatch whereas the plant counts are for caterpillars of any size. A caterpillar probably feeds for about 2-3 weeks prior to pupa formation, depending on temperatures.

Small white butterfly, cabbage moth, garden pebble moth

Comparisons between the periods when small white butterfly, cabbage moth and garden pebble moth caterpillars were found and forecasts of 10% egg hatch and 90% pupation (for meteorological stations at Chivenor (Devon), Charing (Kent), Crosby (Lancashire) and Holbeach (Lincolnshire) respectively) are shown in **Tables 2-4**. In general, caterpillars were found during the periods when most caterpillars would be expected using the forecasts (between 10% egg hatch and 90% pupation). If anything, the cabbage moth was the least predictable species, but this may be due to the small numbers of caterpillars found.

© 2001 Horticultural Development Council

Table 2. The periods during which second and third generation small white butterfly caterpillars were found on plants compared with forecast predictions.

	Period when caterpillars found	Gen 2 10 % caterpillars	Gen 2 90% pupae	Gen 3 10% caterpillars	Percentage caterpillars found outside 10-90% range
1999					
Devon	11 Aug-8 Sep	5 Aug	19 Sep	27 Sep	0
Kent	16 Jul-4 Oct	28 Jul	2 Sep	10 Sep	8
Lancashire	6 Aug-21 Sep	4 Aug	24 Sep	6 Oct	0
Lincolnshire					
Holbeach		2 Aug	16 Sep	25 Sep	
Kirton	19 Aug-7 Oct	4 Aug	20 Sep	29 Sep	0
Butterwick	4 Aug-29 Sep	“	“	“	0
Donington	None				
Moulton	4-11 Aug	“	“	“	0
Wainfleet	28 Jul – 13 Oct	“	“	“	17
2000					
Devon	25 Jul-5 Sep	31Jul	11 Sep	18 Sep	7
Kent	28 Jul-9 Oct	5 Aug	17 Sep	22 Sep	3
Lancashire	9 Aug-7 Sep	4 Aug	19 Sep	29 Sep	0
Lincolnshire					
Kirton	3 Aug-21 Sep	16 Aug	18 Oct		26
Butterwick	None				
Holbeach	3 Aug-18 Oct	10 Aug	14 Oct	27 Sep	0

© 2001 Horticultural Development Council

Table 3. The periods during which cabbage moth caterpillars were found on plants compared with forecast predictions.

	Period when caterpillars found	Gen 1 10 % caterpillars	Gen 1 90% pupae	Gen 2 10% caterpillars	Percentage caterpillars found outside 10-90% range
1999					
Kent	6 Sep-4Oct	17 Jun	10 Aug	2 Sep	0
Lincolnshire					
Kirton	15 Jul-19 Aug	22 Jun	23 Aug	19 Sep	0
2000					
Devon	None	16 Jun	17 Aug	8 Sep	-
Kent	7 Jul-9 Oct	17 Jun	24 Aug	15 Sep	13
Lancashire	24 Aug-31 Aug	18 Jun	26 Aug	14 Sep	63
Lincolnshire					
Kirton	22 Jun-18 Oct	24 Jun	3 Sep	28 Sep	20
Butterwick	None				
Holbeach	23 Aug-28 Sep	19 Jun	29 Aug	19 Sep	11

Table 4. The periods during which garden pebble moth caterpillars were found on plants compared with forecast predictions.

	Period when caterpillars found	Gen 1 10 % caterpillars	Gen 1 90% pupae	Gen 2 10% caterpillars	Gen 2 90% pupae	Percentage caterpillars found outside 10-90% range
1999						
Kent	21 Sep-4 Oct	26 May	18 Jul	7 Aug	2 Oct	24
Lincolnshire						
Donington	9-16 Sep	27 May	21 Jul	13 Aug	18 Oct	0
2000						
Devon	25 Jul-15 Aug	19 May	17 Jul	9 Aug	6 Oct	9
Kent	None	3 Jun	22 Jul	16 Aug	24 Oct	-
Lancashire	None	2 Jun	24 Jul	16 Aug	27 Oct	-
Lincolnshire						
Kirton	None	5 Jun	31 Jul	22 Aug	12 Nov	-
Butterwick	6 Jul-28 Sep					0
Holbeach	29 Jun-2 Oct	4 Jun	27 Jul	18 Aug	3 Nov	1

© 2001 Horticultural Development Council

Some graphical comparisons were made for the small white butterfly and garden pebble moth forecasts using the mmonitoring data collected in south Lincolnshire during 1996-98 as part of the HRI Kirton Pest Monitoring Service (for years when sufficient insects were sampled). The data for all the Lincolnshire sites sampled in a single year were combined. In general, predictions were acceptable (*Appendices 12-13*).

Objective 3. Determine whether it would be possible to use trap catches of adults to determine the risk of caterpillar damage in particular localities.

3.1 Calculate the numbers of adults captured and the numbers of caterpillars found per plant at each monitoring site. Use data collected during the current project and during the previous LINK project (FV 163). (HRI)

The data from all sites were collated. The numbers of adults captured and eggs, caterpillars and pupae found/plant were calculated for each site. The data sets available at present are as follows:

Years	County	Site	No. data sets
1995-1997	Yorkshire	HRI Stockbridge House	3
1995-2000	Lincolnshire	HRI Kirton	6
1995-1997	Cambridgeshire	ADAS Arthur Rickwood	3
1995-1997	Warwickshire	HRI Wellesbourne	3
1996-2000	Lincolnshire	Commercial crops x 4 (2 in 2000)	18
1999-2000	Devon	Commercial crop	2
1999-2000	Kent	Commercial crop	2
1999-2000	Lancashire	Commercial crop	2
		Total sites	**39**

Obviously not all species were present at every site.

3.2 Use regression and other statistical techniques to determine the relationship between the number of adults captured and the numbers of caterpillars infesting untreated plants in the monitoring plots. (HRI)

3.3 Determine whether this relationship is consistent between sites and years. (HRI)

The intention was to identify correlations between trap catches and the numbers of caterpillars in adjacent insecticide-free brassica plots. However, as would be expected, the data were very variable. Without doing extremely complex analyses based on the rate of

© 2001 Horticultural Development Council

caterpillar development, there are two parameters that can be compared directly 1) the peak numbers in any ‘generation’ and 2) the total numbers in a ‘generation’. Whereas the capture of moths is a ‘unique’ event and they cannot be re-sampled subsequently, the caterpillars may be observed on several sampling occasions and this biases the ‘totals’ data considerably. In particular, caterpillars with long life cycles may be observed for several weeks and give a false impression of the size of the infestation. Thus the ‘total numbers’ cannot be used reliably. Comparisons were made therefore between the peak numbers of adults/eggs found in any generation and the peak numbers of caterpillars (generally found some time later) to see if these would provide some general guidelines for each species. A total of 0.25 caterpillars/plant was chosen as an arbitrary lower threshold. A mean infestation level of 0.25 caterpillars/plant is broadly equivalent to 10-20% plants being infested with one or more caterpillars.

Diamond-back moth

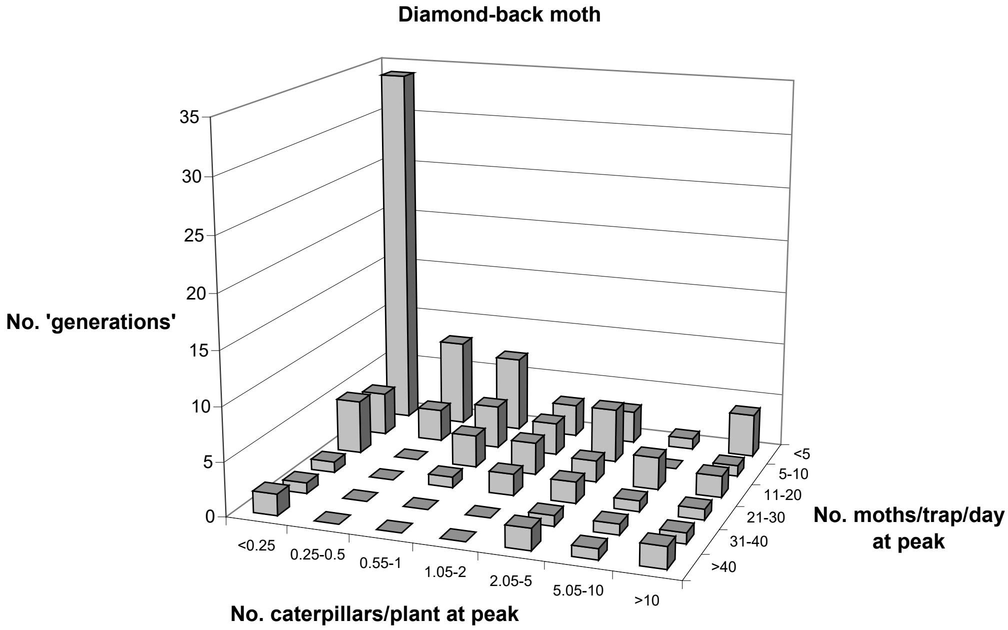
The diamond-back moth was the most numerous pest caterpillar during 1995-2000 and provided the largest data set. The monitoring data were summarised by separating the periods of moth and caterpillar activity into generations. There was an average of 35±13 days between the dates when peak numbers of first and second generation caterpillars were found and 39±19 days between the second and third generations.

The numbers of moths captured/trap/day and the numbers of caterpillars found/plant at each peak were determined. Peak numbers of first generation moths were captured between 14 May and 11 August, depending on the year and site. On average, peak numbers of caterpillars were found 16, 15 and 27 days after peak numbers of moths were captured, during the first, second and third generations respectively.

The peak numbers of moths captured in each generation at each site were compared with the peak numbers of caterpillars in a contingency table, which is a method of categorising the data to show how they are distributed. The results are summarised in Fig 1. About 40% of all ‘generations’ had < 0.25 caterpillars/plant at the peak. Where <5 moths/trap/day were captured at the peak then 56% of these ‘generations’ had < 0.25 caterpillars and 82% had < 1 caterpillar/plant at the peak. In contrast, where >20 moths/trap/day were captured at the peak, 74% ‘generations’ had >1 caterpillar/plant. Lowering the moth threshold to <3 moths/trap/day did not increase the percentage of ‘generations’ with < 0.25 caterpillars.

© 2001 Horticultural Development Council

Fig 1. The relationship between the numbers of diamond-back moths trapped and the numbers of caterpillars found/generation.



Small white butterfly

Adult butterflies were captured in water traps and the numbers of eggs, caterpillars, pupae and adults were recorded on plants in the insecticide-free plots. Periods of activity were divided into two 'generations'. An average of 0.08 butterflies/trap/day were captured at the peak of the first generation and 0.73 during the second generation. Similarly, 0.04 caterpillars/plant were found at the peak of the first generation and 0.63 at the peak of the second generation. Egg counts were 0.07 and 0.4/plant respectively.

The peak numbers of butterflies or eggs recorded in each generation were compared with the peak numbers of caterpillars in a contingency table. The results are summarised in Figs 2 & 3. A large proportion of 'generations' (70%) had < 0.25 caterpillars/plant at the peak. Where <0.2 butterflies/trap/day were captured at the peak, 75% of these 'generations' had < 0.25 caterpillars/plant. Where < 0.25 eggs/plant were found at the peak, then peak numbers of caterpillars were <0.25 in 84% 'generations'.

© 2001 Horticultural Development Council

Fig 2. The relationship between the numbers of small white butterflies trapped and the numbers of caterpillars found/generation.

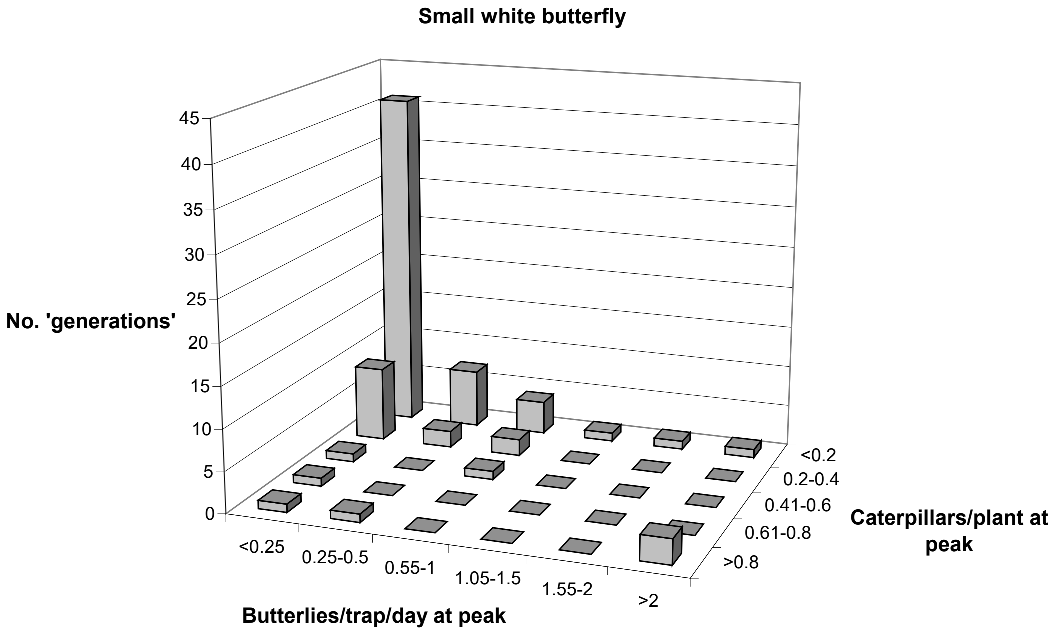
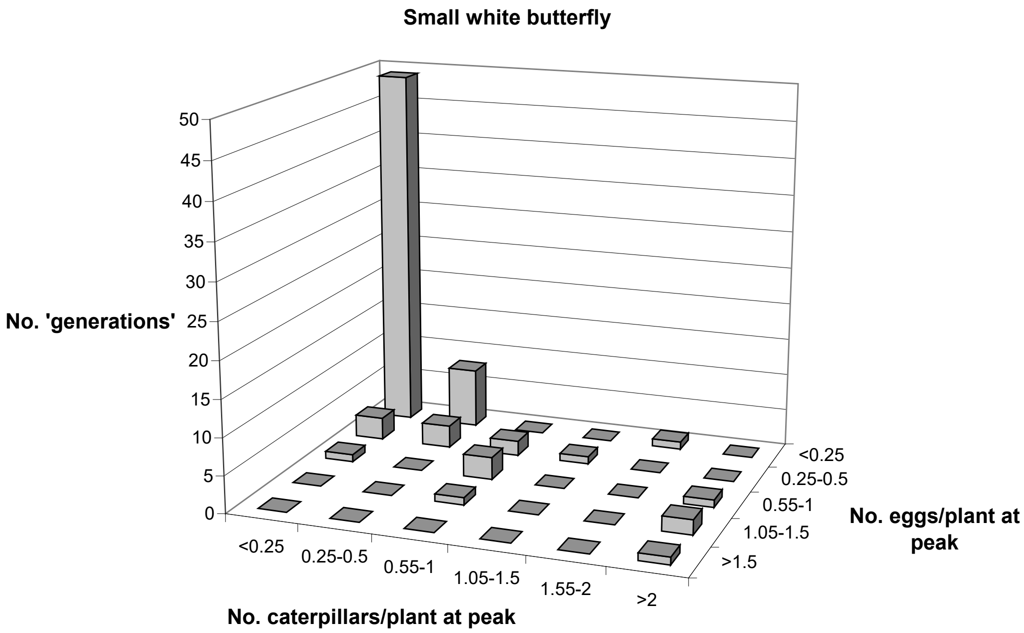


Fig 3. The relationship between the numbers of small white butterfly eggs and caterpillars found/generation.



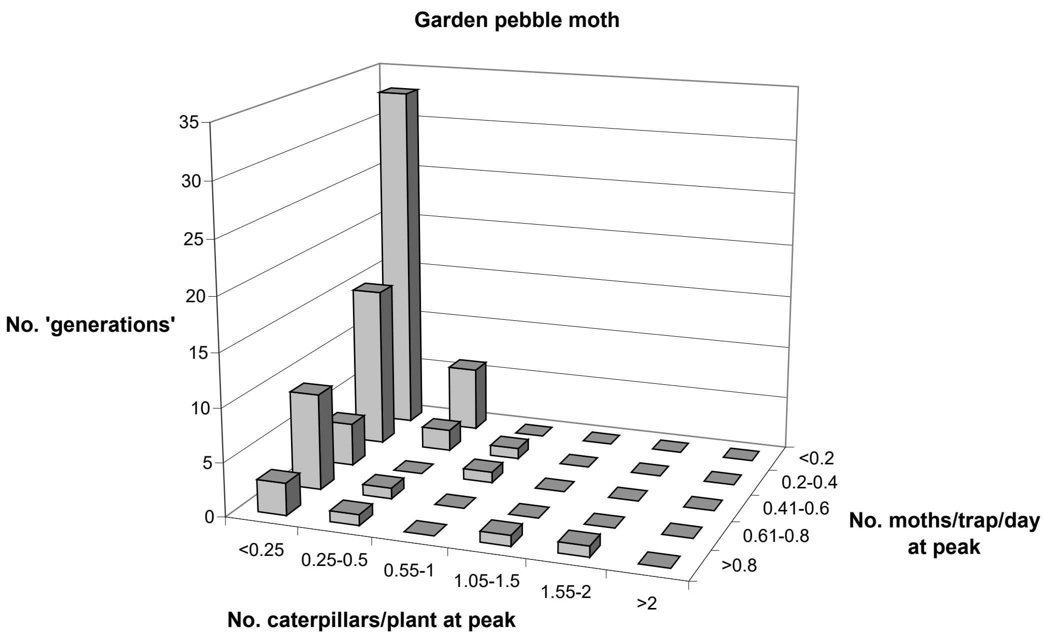
Garden pebble moth

Adult moths were captured in pheromone traps, which are relatively selective for this species, and the numbers of caterpillars were recorded on plants in insecticide-free plots.

© 2001 Horticultural Development Council

An average of 5.3 moths/site was captured at the time of the first generation and 11.4 during the second generation. An average of 0.035 caterpillars/plant was found at the peak of the first generation and 0.22 at the peak of the second generation. The peak numbers of moths recorded in each 'generation' were compared with the peak numbers of caterpillars in a contingency table. The results are summarised in Fig 4. A large proportion of 'generations' (82%) had <0.25 caterpillars/plant. Where <0.2 moths/trap/day were captured at the peak, 85% 'generations' were infested with <0.25 caterpillars and 100% were infested with 0.5 caterpillars/plant or less. The only two heavily infested site/generation combinations (> 1 caterpillar/plant at peak) were those where more than 0.8 moths/day were captured in pheromone traps.

Fig 4. The relationship between the numbers of garden pebble moths trapped and the numbers of caterpillars found/generation.



Cabbage moth

The cabbage moth pheromone traps were relatively ineffective. For example, in previous studies (FV 163), very few moths were captured in pheromone traps, although caterpillars were observed in insecticide-free plots at several sites. Less than 0.25 caterpillars/plant were found in 86% of 'generations'.

Silver Y moth

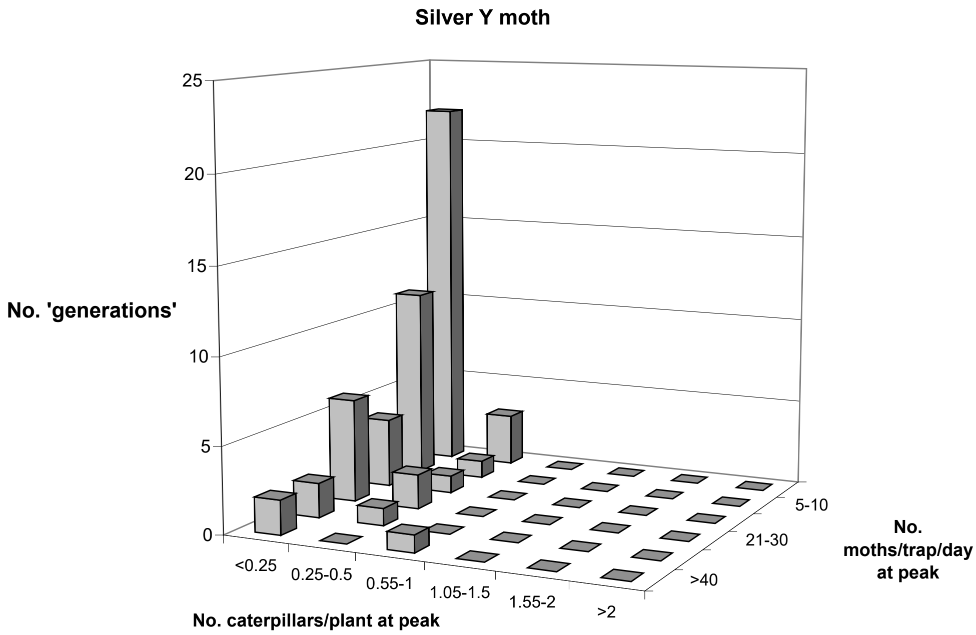
The silver Y moth pheromone traps were selective and captured relatively large numbers of moths. The data were divided into two 'generations' and means of 19 and 8 moths/day were captured at the peaks of the first and second generations respectively, corresponding

© 2001 Horticultural Development Council

to 0.15 and 0.13 caterpillars/plant. The peak numbers of moths recorded in each 'generation' were compared with the peak numbers of caterpillars in a contingency table. The results are summarised in Fig 5.

A large proportion of sites (84%) had < 0.25 caterpillars/plant, although pheromone trap captures of moths were very variable. However, where <5 moths/trap/day were captured at the peak, plants were infested with <0.25 caterpillars/plant at the peak in 88% of these 'generations' and with no more than 0.5 caterpillars/plant at 100% sites. None of the 50 site/generation combinations for which there were pheromone trap and caterpillar data had > 1 caterpillar/plant at the peak. However, one of the additional 26 site/generation combinations that had no pheromone trap data had 4.5 caterpillars/plant at the peak.

Fig 5. The relationship between the numbers of silver Y moths trapped and the numbers of caterpillars found/generation.



DISCUSSION

Caterpillar infestations were light during 1999 at all of the monitoring sites. This makes forecast validation more difficult because estimates of the timing of each generation are less accurate when insect numbers are small. Infestations were greater in 2000 for most species.

© 2001 Horticultural Development Council

As there were no instances where more than one caterpillar/plant was found in 1999, this implies that few insecticide treatments would have been required for caterpillar control. This was supported by the results of supervised control experiments at HRI Kirton (FV 194), where few sprays were applied to control caterpillars and even the insecticide-free control plot suffered very slight damage at harvest.

Although all six species of caterpillar infest vegetable brassicas, their life cycles, and the risk of damage, vary considerably. This study confirms the results of the previous LINK project (FV 163), which showed that, overall, the diamond-back moth was the most numerous pest of brassica crops, followed by the small white butterfly. Even though silver Y moth adults are captured in large numbers in pheromone traps, the caterpillars do not appear to be damaging pests of brassicas. The caterpillars are not restricted to brassica crops and are found on a wide range of hosts including sugar beet and lettuce. Both the cabbage moth and garden pebble moth are ‘localised’ pests and the risk of attack may be estimated best from the occurrence of previous infestations in the locality. The large white butterfly does not appear to be important commercially.

Although diamond-back and silver Y moth migrations are undoubtedly originating from the ‘east’ (continental Europe) and Lincolnshire is usually the most affected area, these species were still found in Lancashire and Devon. Because the diamond-back moth is a migrant species, pheromone traps are the most effective way of determining when infestations will occur and the current diamond-back moth model uses moth counts to trigger a forecast of subsequent population development. For the purposes of forecast validation, moth counts from the first migration were used to predict the timing of the subsequent generations. This is not necessarily the way that the model would be used in practice, since moth captures would probably be added on a weekly or more frequent basis. This study also confirms observations made in Project FV 163, that female diamond-back moths are laying eggs at the time that male moths are captured in pheromone traps. Similarly, pheromone trap catches of the silver Y moth could be used to trigger a forecast to indicate when caterpillars of this pest might be expected. This might be of more value to salad growers than brassica growers.

For the other species that overwinter in the UK (small white butterfly, cabbage moth, garden pebble moth), the forecast programs use air and soil temperatures accumulated from 1 February each year. For these species, the forecasts can be used to indicate the periods when the largest numbers of caterpillars might be expected and when crop walking should be targeted. Crops most at risk are likely to have a history of these pests at the site.

The second aim of this project was to determine whether monitoring data could be used to indicate the likely size of infestations and thus give advance warning of the need to prevent

© 2001 Horticultural Development Council

damage. Adult trapping data for the cabbage moth and small white butterfly appear to be extremely variable and are probably unreliable indicators. The reason for the poor performance of water traps in capturing small white butterflies is unclear. Egg samples may provide a more reliable indication for both species (although there are few cabbage moth data to support this suggestion). For the diamond-back moth, silver Y moth and garden pebble moth, adult traps are much more effective and specific. Although garden pebble moth captures were low generally, this appears to reflect only the relative rarity of this species as a pest.

The relationships between the peak numbers of adults/eggs found in each generation and the peak numbers of caterpillars were very variable. This is not unexpected and is the result of 1) random sampling error, 2) the relatively long (weekly) sampling interval, 3) the differential effects of natural mortality factors (and in some cases, insecticide spray drift) on survival of the immature stages, and 4) sampling variation due to differences between observers. However, these data may be used to give some general guidelines for growers, summarised in **Table 5.**

CONCLUSIONS

- The data collected in 1999 and 2000 confirm that the diamond-back moth and small white butterfly are the most widespread caterpillar pests of brassicas in the UK. The silver Y moth is common also. The cabbage moth and garden pebble moth are localised pests. The large white butterfly occurs rarely in commercial brassica crops.
- Caterpillar infestations were slight in 1999 and there were no instances where more than one caterpillar of each species/plant was found. This implies that few insecticide treatments would have been required for caterpillar control. This was supported by the results of supervised control experiments at HRI Kirton (FV 194), where few sprays were applied to control caterpillars and even the insecticide-free control plot suffered very slight damage.
- Diamond-back moth caterpillars were present in crops from late June until October. This is a migrant species and the timing of immigration varies from year to year. Pheromone traps should be used to indicate when large numbers of moths are entering crops since female diamond-back moths will lay eggs at the same time that the traps are capturing male moths. Diamond-back moth development is rapid. The diamond-back moth forecast, which is triggered by moth trap captures, can be used to predict when caterpillars will be found and when the next generation is likely to occur. The relationship between the numbers of moths captured in pheromone traps and the numbers of caterpillars found subsequently on plants in insecticide-free plots was not particularly consistent.

© 2001 Horticultural Development Council

- Most of the small white butterfly caterpillars found on plants were the progeny of either the second or third generations, confirming that the first generation is the least important numerically. There appears to be a fairly consistent relationship between the numbers of eggs found on plants and the numbers of caterpillars found subsequently, so egg sampling could give an indication of subsequent caterpillar numbers. The small white butterfly forecast can be used to indicate the periods when eggs are being laid and when caterpillars are likely to be found.
- Silver Y moths were captured at every site. They are also migrant moths and the timing of immigration varies from year to year. Previous studies suggested that the caterpillars are not important pests of brassicas. Although moth numbers were often relatively high, none of the 50 site/generation combinations for which there were pheromone trap and caterpillar data had > 1 caterpillar/plant at the peak. However, one of the additional 26 site/generation combinations that had no pheromone trap data had 4.5 caterpillars/plant at the peak.
- Both the cabbage moth and garden pebble moth are localised pests. If crops in the locality have been infested previously, the risk of attack is likely to be increased. Pheromone traps for the cabbage moth appear to be relatively non-specific and ineffective, whereas those for the garden pebble moth are specific and appear to give a good indication of the likelihood of infestation by caterpillars. The forecasts for both pests could be used to indicate the periods when egg laying is likely to occur and when caterpillars can be found. The cabbage moth model has been the most difficult to validate reliably as infestations have been so small.
- The large white butterfly does not appear to be important commercially.

© 2001 Horticultural Development Council

Table 5. Guidelines for forecasting and monitoring the pest caterpillars of brassicas.

	Diamond-back moth	Small white butterfly	Cabbage moth	Garden pebble moth	Silver Y moth	Large white butterfly
1. Adult trap	Pheromone	Water	Pheromone	Pheromone	Pheromone	Water
2. Trap selectivity	High	Low	Low	High	High	Low
3. Other counts		Eggs	Eggs		Eggs	Eggs
4. Distribution in field	Random	Random	Clumped	Clumped	Random	Clumped
5. Overwintering	Migrant	UK	UK	UK	Migrant	UK
6. Occurrence	Widespread	Widespread	Localised	Localised	Widespread	Localised
7. Tentative guidelines (<0.25 caterpillars per plant)	<5 moths per trap per day (56% sites)	<0.2 butterflies per trap per day (75% sites) <0.25 eggs per plant (84% sites)	Trap captures unreliable	<0.2 moths per trap per day (85% sites)	<5 moths per trap per day (85% sites)	None
8. Forecast	Yes	Yes	Yes	Yes	No	No
9. Met data required	Air max/min	Air max/min	Air max/min & soil	Air max/min & soil		
10. Triggered by	Trap captures	Spring temperature	Spring temperature	Spring temperature		

1. Pheromone traps are available for all the pest moths. Full instructions are supplied with the traps. Butterflies can be captured in water traps but growers can also see when they are flying around in large numbers.
2. Some of the pheromone traps are very selective and only catch the target pest (with a few strays), so you do not need to know how to identify the moths. Others are less selective and if growers are unable to separate out the right species, the counts can be very misleading.
3. With some species the eggs are quite easy to see when growers are inspecting the leaves for pests and disease.
4. Some species are more ‘clumped’ than others, mainly because the eggs are laid in groups rather than singly. The caterpillars tend to spread out from the egg-laying plant as they feed and grow.
5. Some species overwinter in the UK (mainly as pupae), whilst others cannot survive the winter and arrive each year as migrants from continental Europe.

© 2001 Horticultural Development Council

6. Some species are widespread, others occur in certain localities. We do not know how much their distribution changes from year to year, but it looks as if certain areas are preferred by these pests, whilst others are not.
7. We have tried to work out tentative 'guidelines' for the various pests based on the relationship between the peak numbers of adults/eggs found in each generation and the peak numbers of caterpillars found subsequently. An infestation of 0.25 caterpillars/plant is broadly equivalent to 10-20% plants being infested (we hope to do some more work on this later in a MAFF project). The percentages in brackets are the percentage of sites where when < 5 moths/trap/day were captured at the peak (for example) peak numbers of caterpillars were <0.25/plant.
8. Forecasts have been developed for four of the species.
9. The forecasts run on air, or air and soil, temperatures.
10. Some of the forecasts need to start accumulating temperatures from 1 February each year (if the insects overwinter in the UK). The forecast for the migrant pest (diamond-back moth) is triggered by pheromone trap captures.

© 2001 Horticultural Development Council

TECHNOLOGY TRANSFER

Publications

COLLIER, R.H. (1999). Caterpillar pests of brassicas. *HDC News* **No. 54**, 18-19.

BLOOD SMYTH, J. A. & **COLLIER, R.H.** (1999). The development of an IPM strategy for cabbage caterpillars on horticultural brassica crops. *The Vegetable Farmer*, October 1999, 20-21.

KENNEDY, R. & **COLLIER, R.H.** (2000). Pests and diseases of field vegetables. In:*Pest and Disease Management Handbook* (Alford, D. (ed)), Blackwell Science/British Crop Protection Council, 615pp.

Presentations

3-Feb-99	Brassica Seminar – HRI Kirton
22-Jun-99	Grower walk at HRI Kirton - brassicas
03-Aug-99	Grower walk at HRI Kirton - brassicas
2-Feb-00	Brassica Workshop in Lancashire (Garstang)
20-Jul-00	Farm walk – HRI Kirton
23-Aug-00	HRIA Organic Day at HRI Kirton
4-Jan-01	HDC/HRIA Workshop Brassica pest control with insecticides
11-Jan-01	HDC/HRIA Workshop Brassica pest control without insecticides
22-Feb-01	Brassica Workshop in Lancashire (Garstang)

ACKNOWLEDGEMENTS

We are very grateful to Jennie Blood Smyth and her colleagues in ADAS for monitoring insects at three of the sites each year, to the growers in Lincolnshire who provided plots of insecticide-free Brussels sprouts for this project and for the HRI Kirton Pest Monitoring Service and to the Horticultural Development Council for supporting this work.

REFERENCES

Blood Smyth, J.A., Davies, J. Emmett, B.J. Lole, M., Paterson, C. & Powell, V. (1992). Supervised control of aphid and caterpillar pests in Brassica crops. *IOBC/WPRS Bulletin 1992* **XV/4**, 9-15.

Blood Smyth, J.A., Emmett, B.J., Mead, A., Davies, J.S., Paterson, C.D. & Runham, S. (1994). Supervised control of aphid and caterpillar pests in Brassica crops. *IOBC/WPRS Bulletin 1994* **XVII/8**, 41-50.

© 2001 Horticultural Development Council

Emmett, B.J. (1992). Integrated pest management of inset pests in brassica crops. *HDC Project FV 119 Final Report*, HDC, East Malling, Kent.

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.*

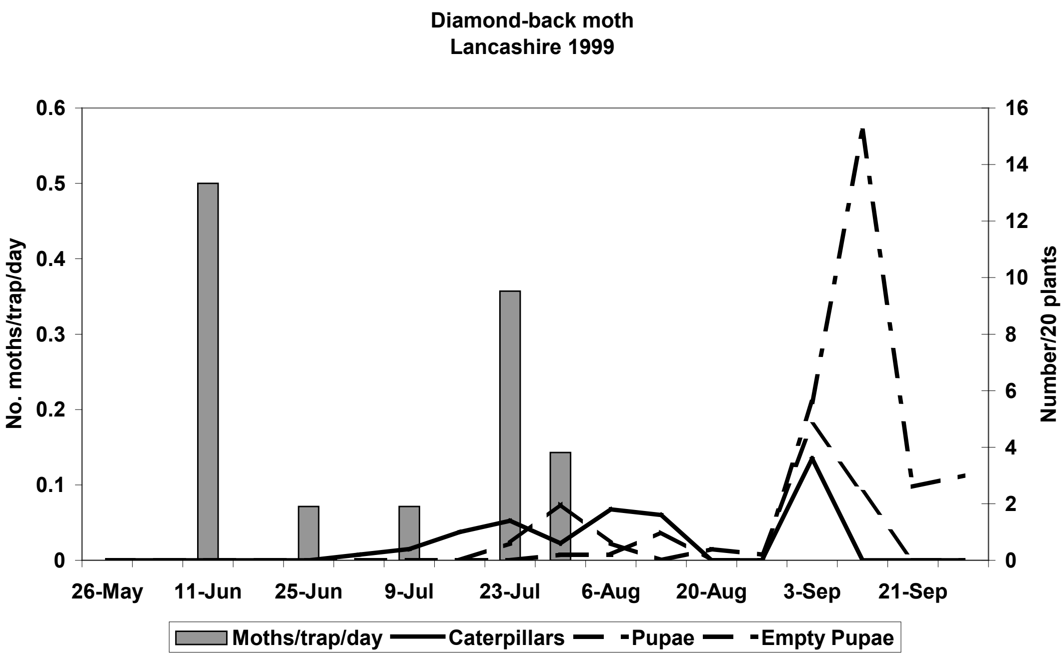
Nix, J. (1998). Farm Management Pocketbook, 29th edition (1999), Wye College, University of London, 232 pp.

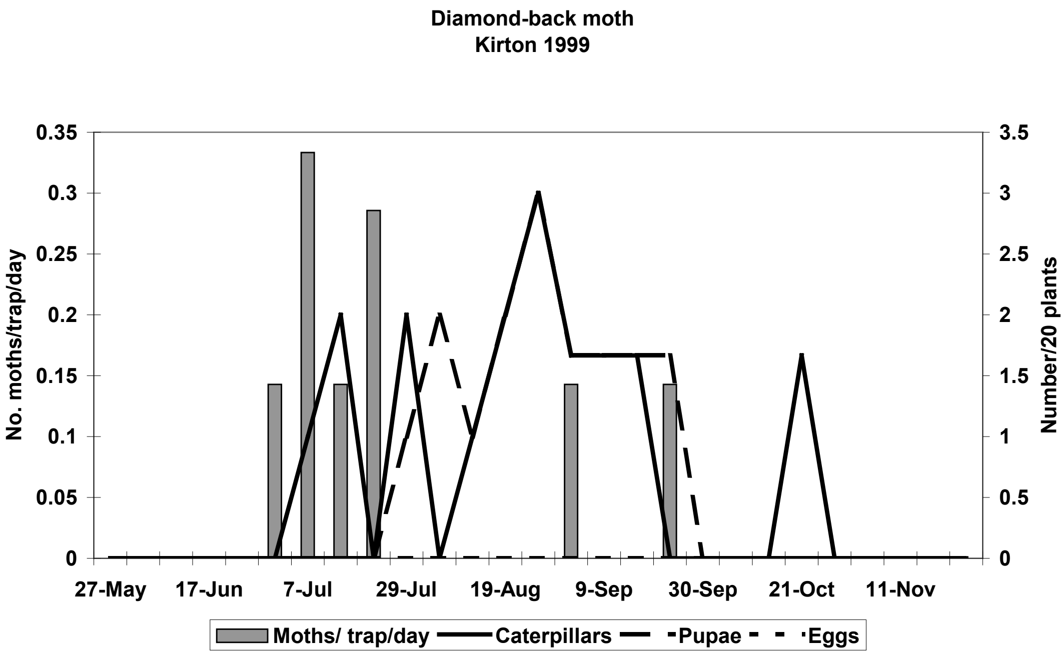
Paterson, C., Mead, A., Blood Smyth, J.A., Davies, J. & Runham, S. (1994). Using a sequential sampling method for supervised control of pests in Brussels sprouts and calabrese. *Aspects of Applied Biology* **37**, 73-82.

© 2001 Horticultural Development Council

APPENDIX

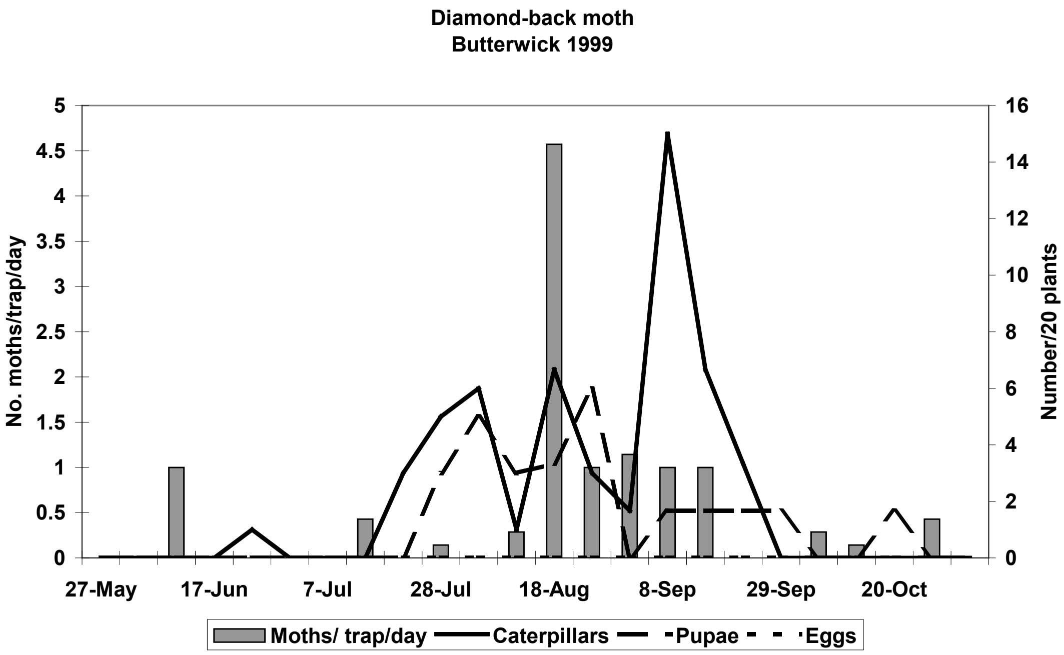
Appendix 1 The numbers of diamond-back moths sampled in 1999.

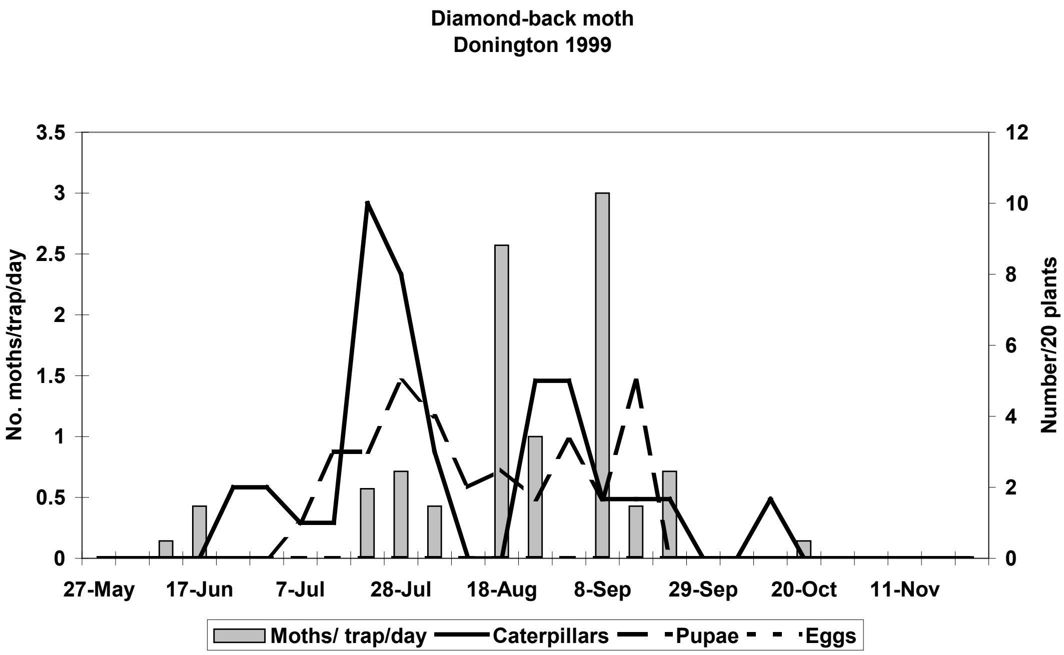




© 2001 Horticultural Development Council

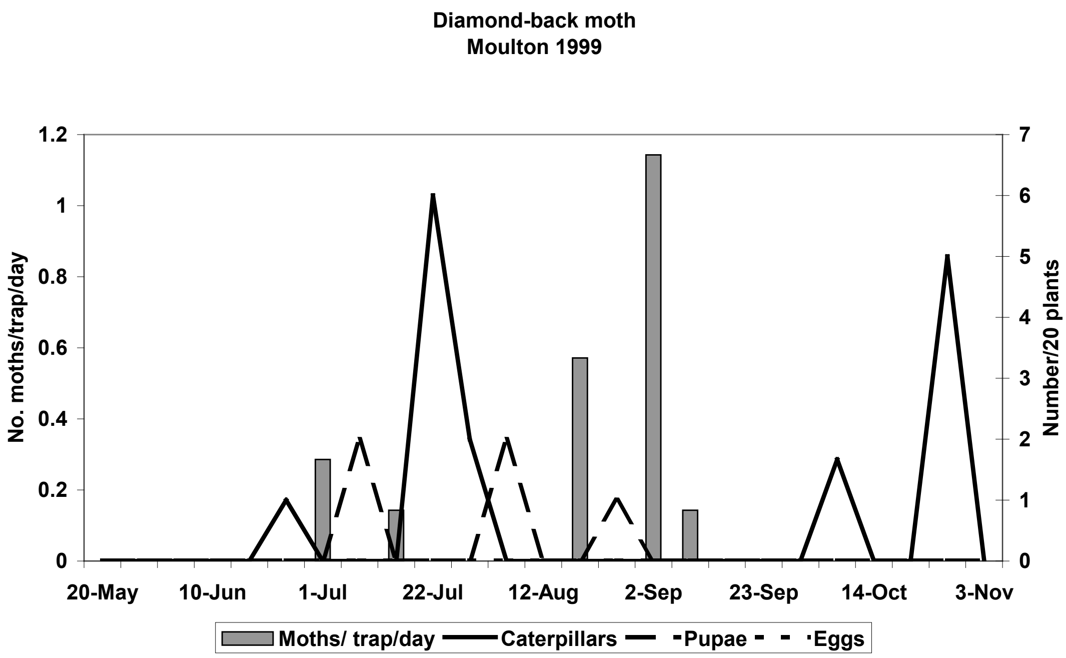
Appendix 1 The numbers of diamond-back moths sampled in 1999.

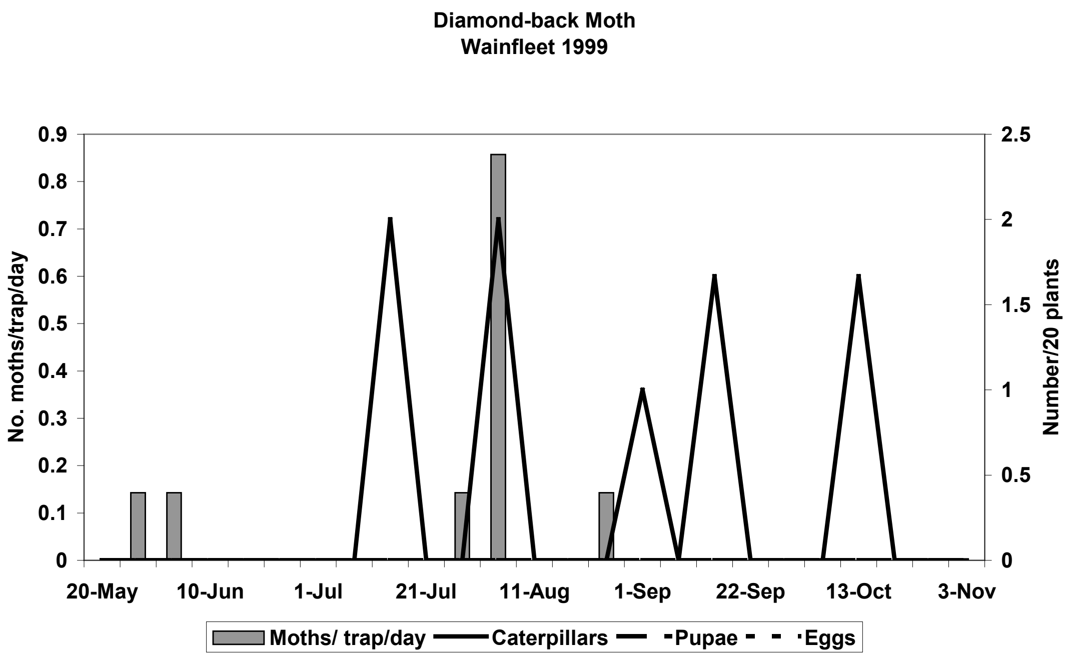




© 2001 Horticultural Development Council

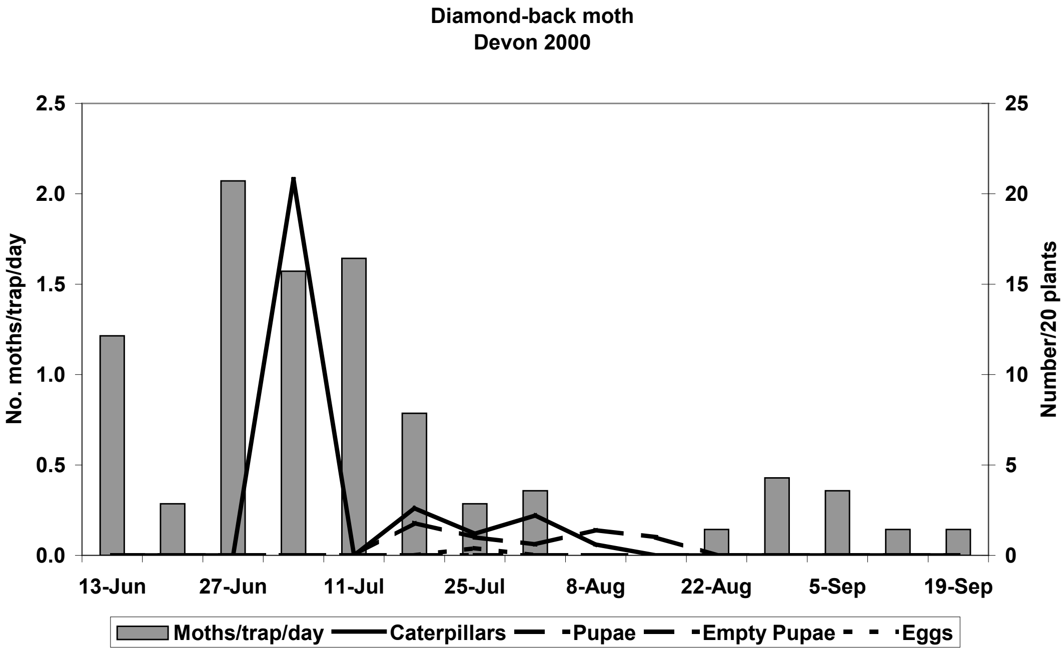
Appendix 1 The numbers of diamond-back moths sampled in 1999.

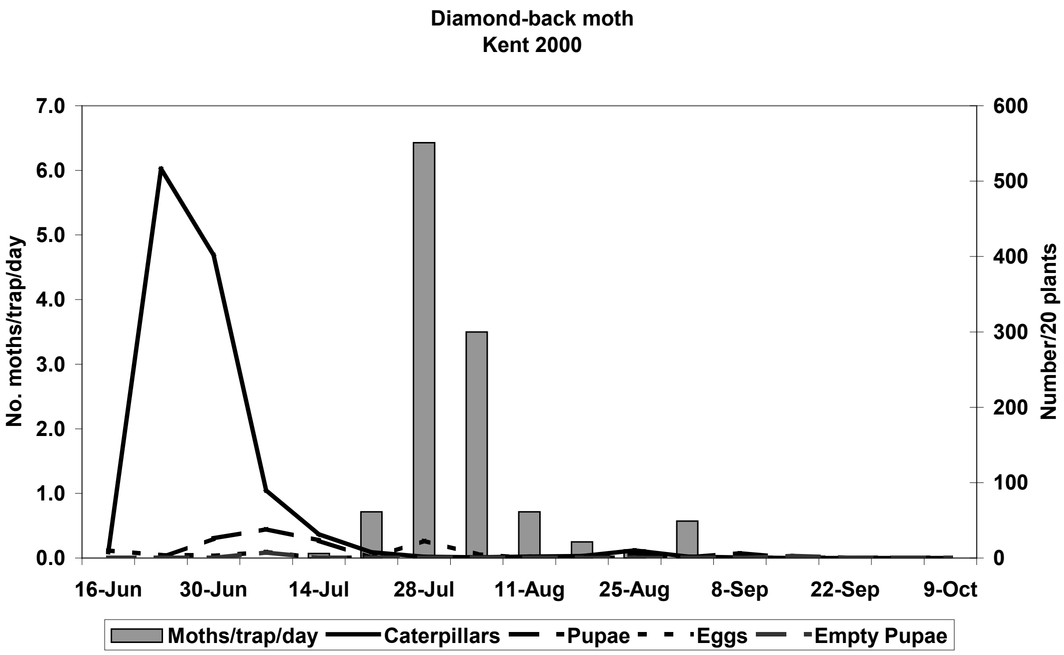




© 2001 Horticultural Development Council

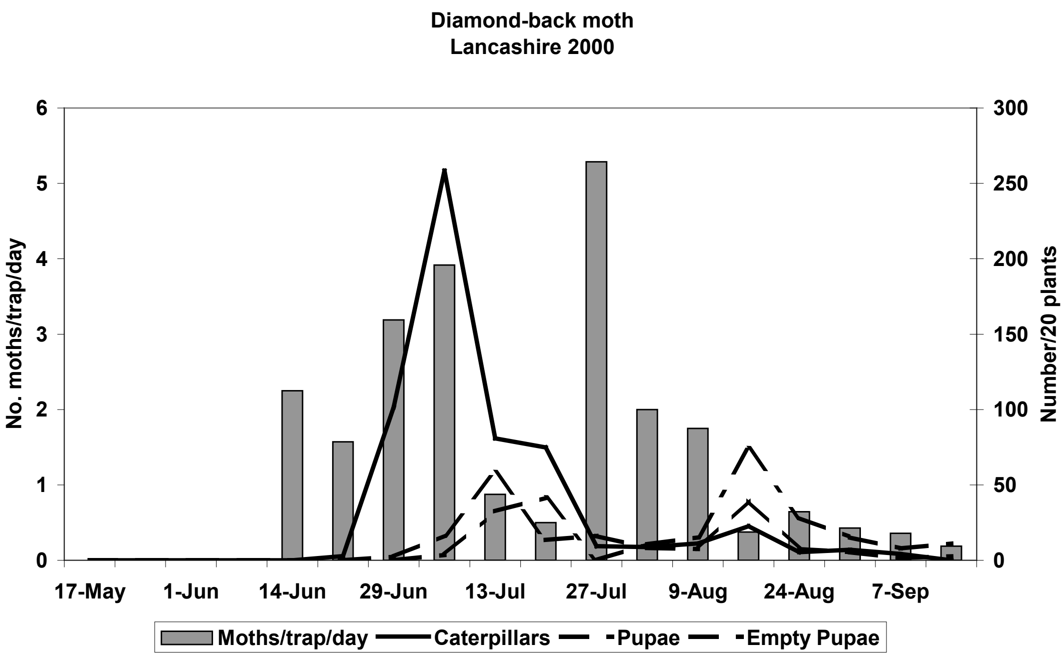
Appendix 2 The numbers of diamond-back moths sampled in 2000.

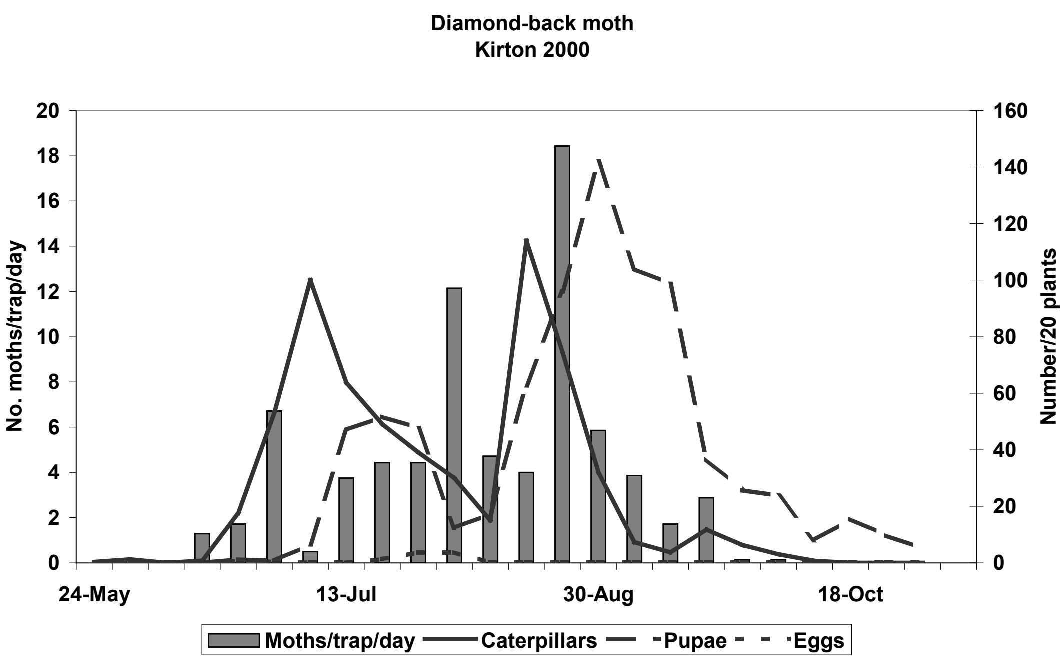




© 2001 Horticultural Development Council

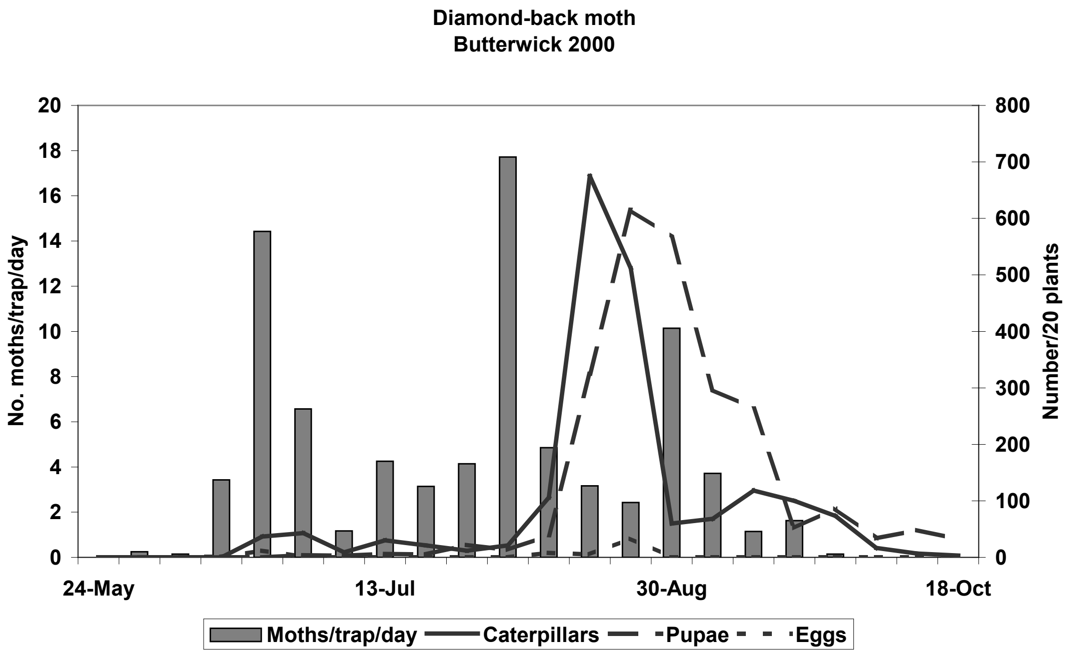
Appendix 2 The numbers of diamond-back moths sampled in 2000.

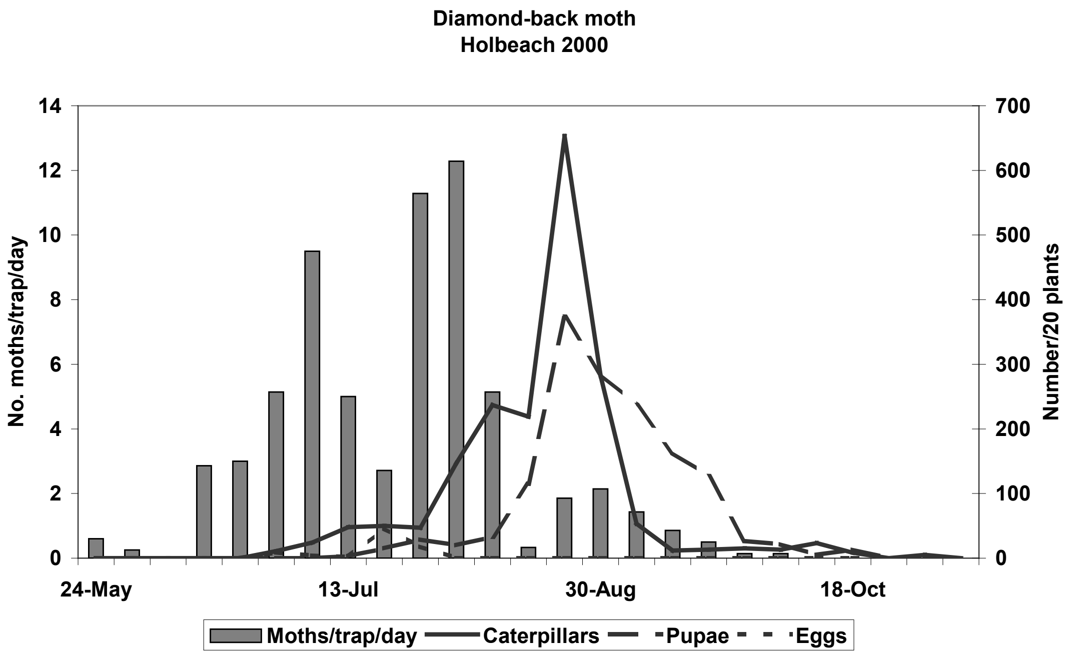




© 2001 Horticultural Development Council

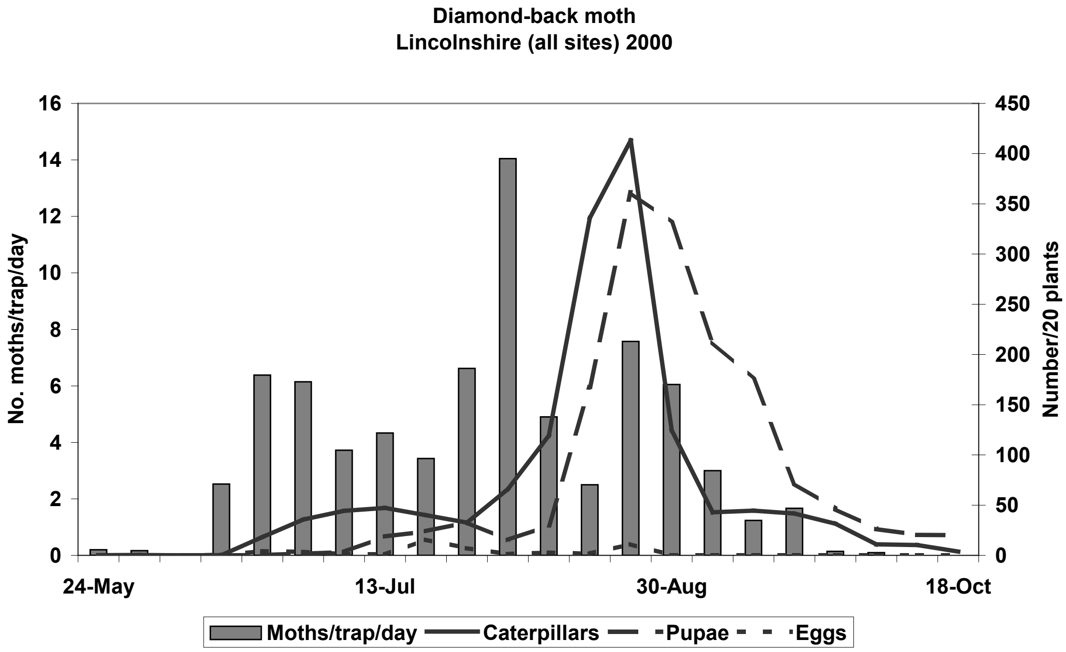
Appendix 2 The numbers of diamond-back moths sampled in 2000.





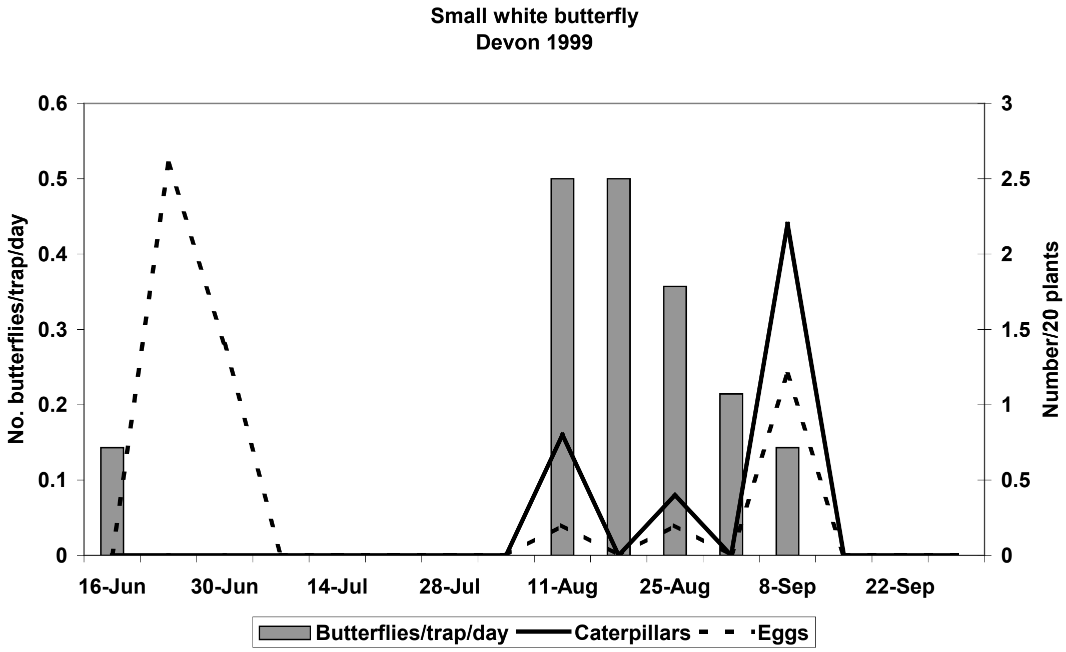
© 2001 Horticultural Development Council

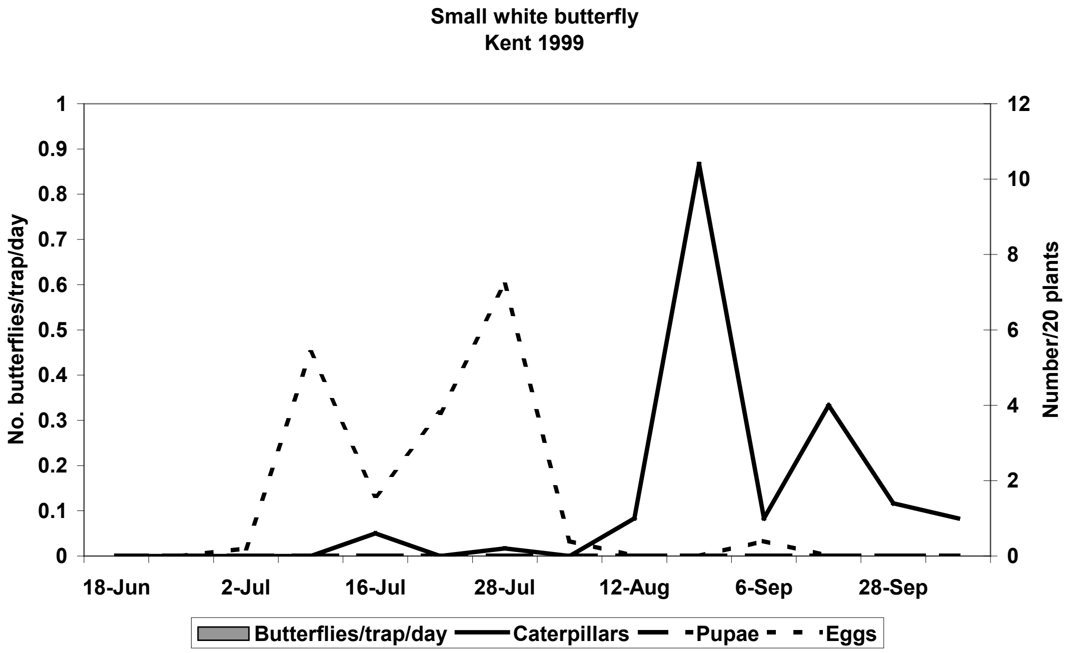
Appendix 2 The numbers of diamond-back moths sampled in 2000.



© 2001 Horticultural Development Council

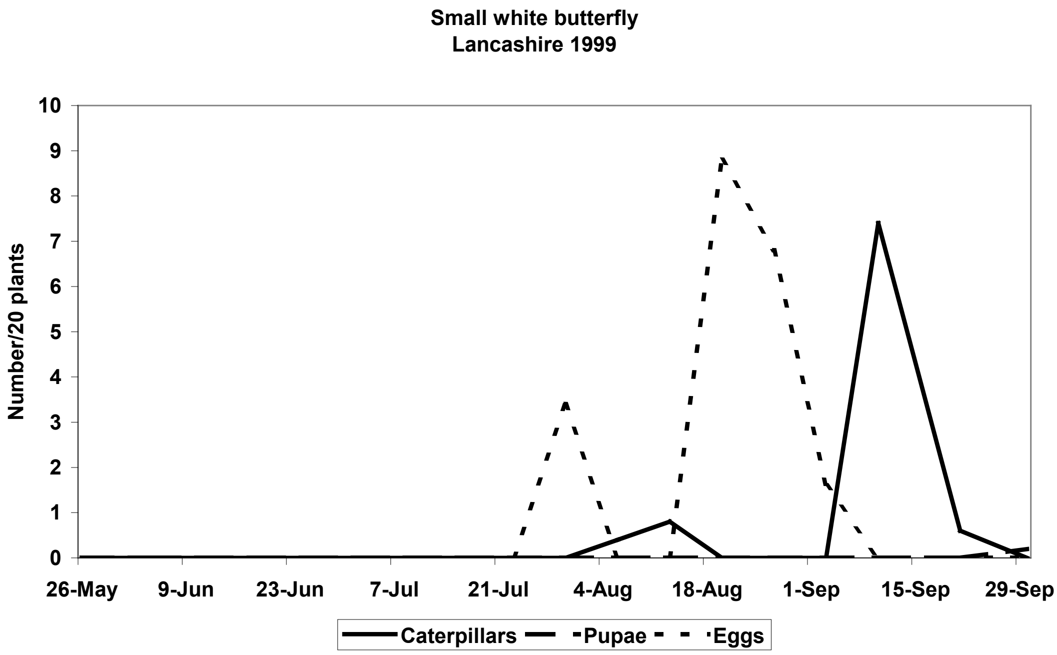
Appendix 3 The numbers of small white butterflies sampled in 1999.

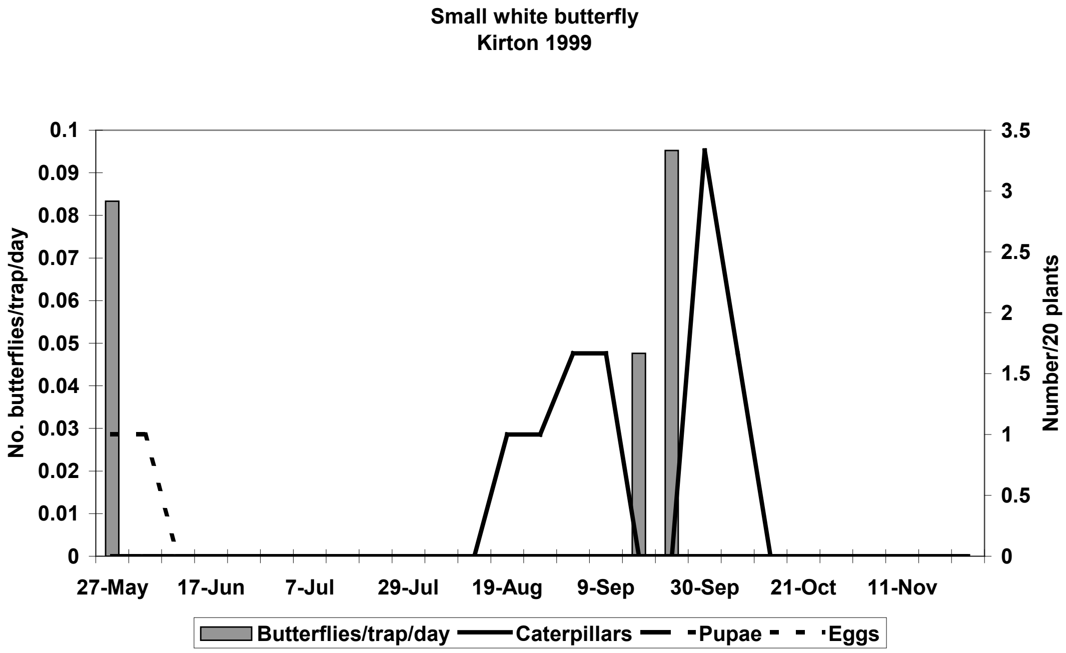




© 2001 Horticultural Development Council

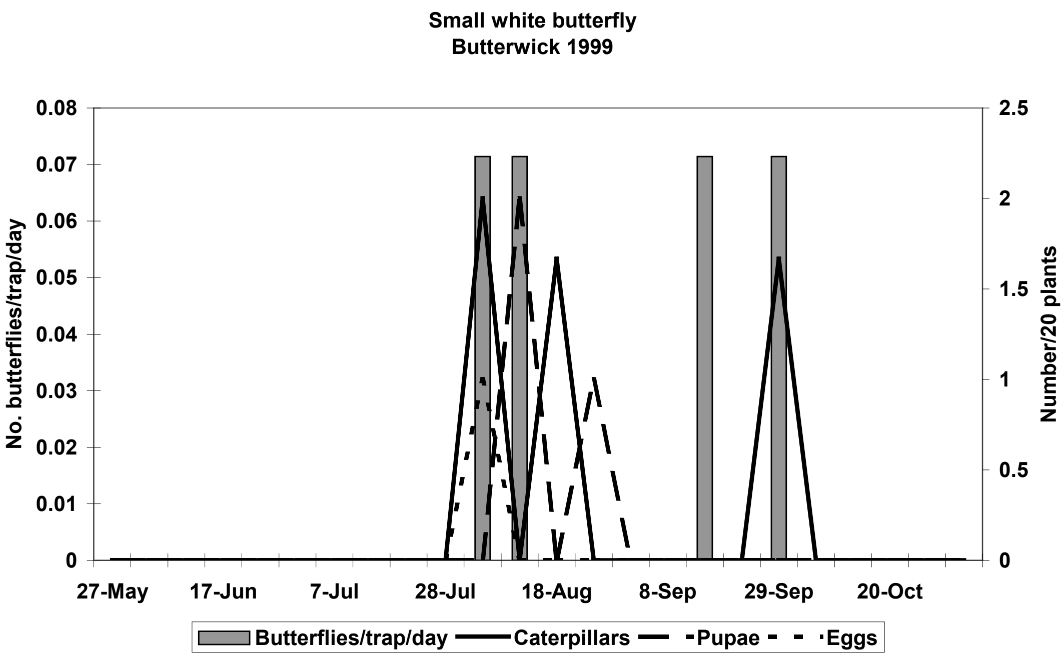
Appendix 3 The numbers of small white butterflies sampled in 1999.

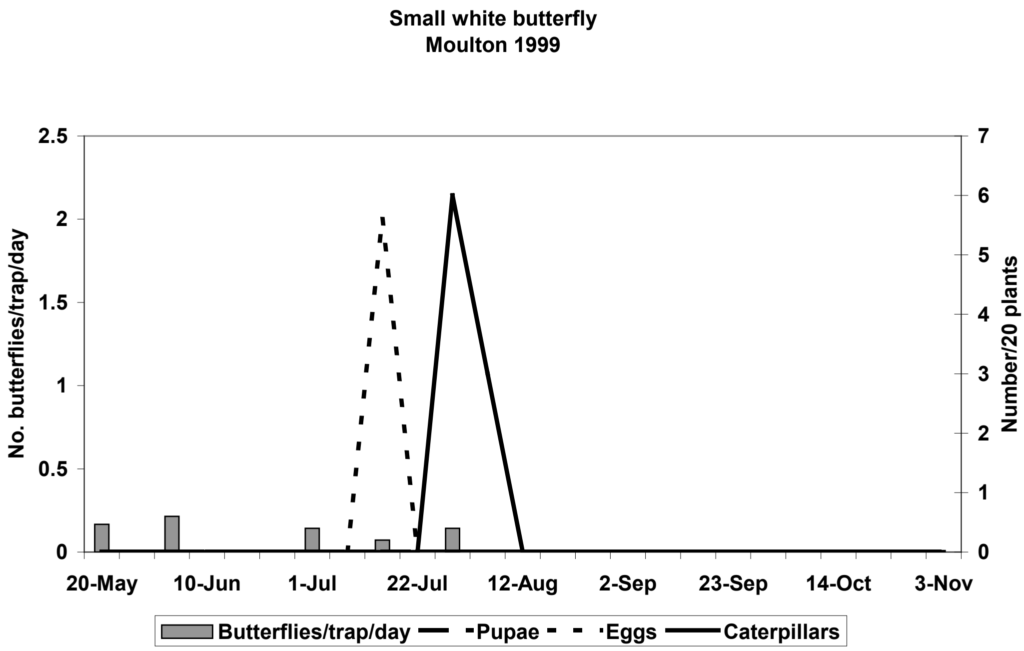




© 2001 Horticultural Development Council

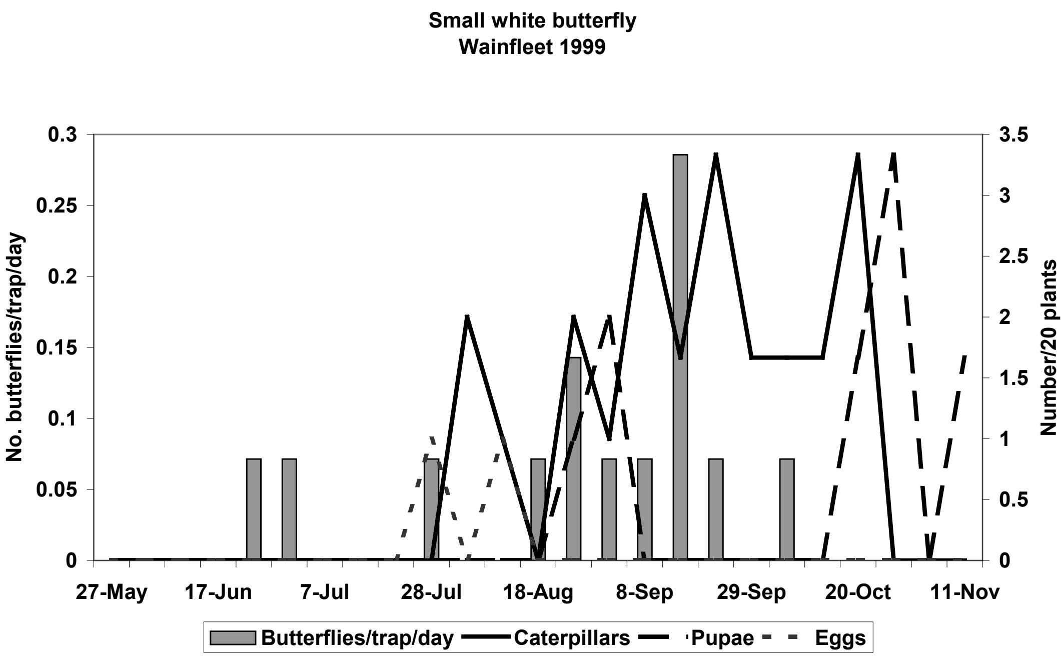
Appendix 3 The numbers of small white butterflies sampled in 1999.





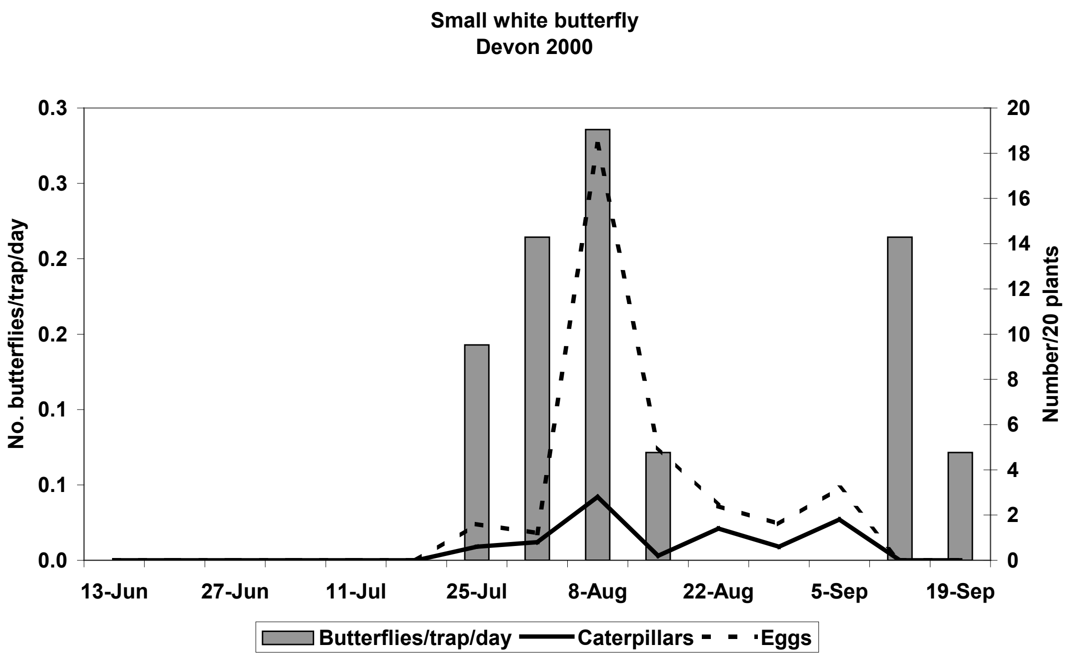
© 2001 Horticultural Development Council

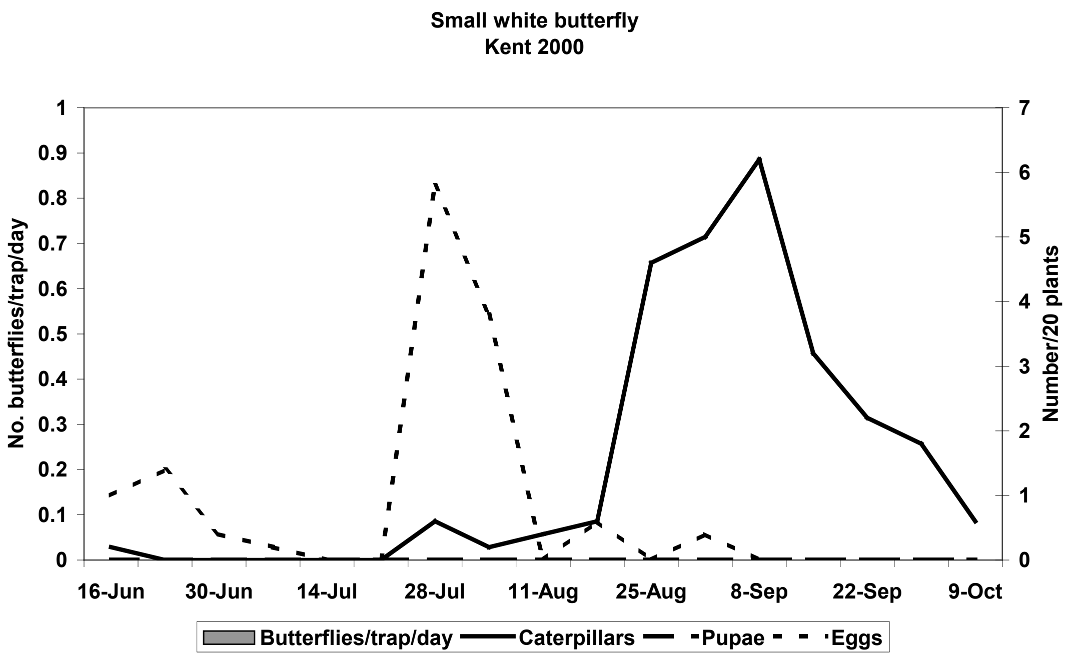
Appendix 3 The numbers of small white butterflies sampled in 1999.



© 2001 Horticultural Development Council

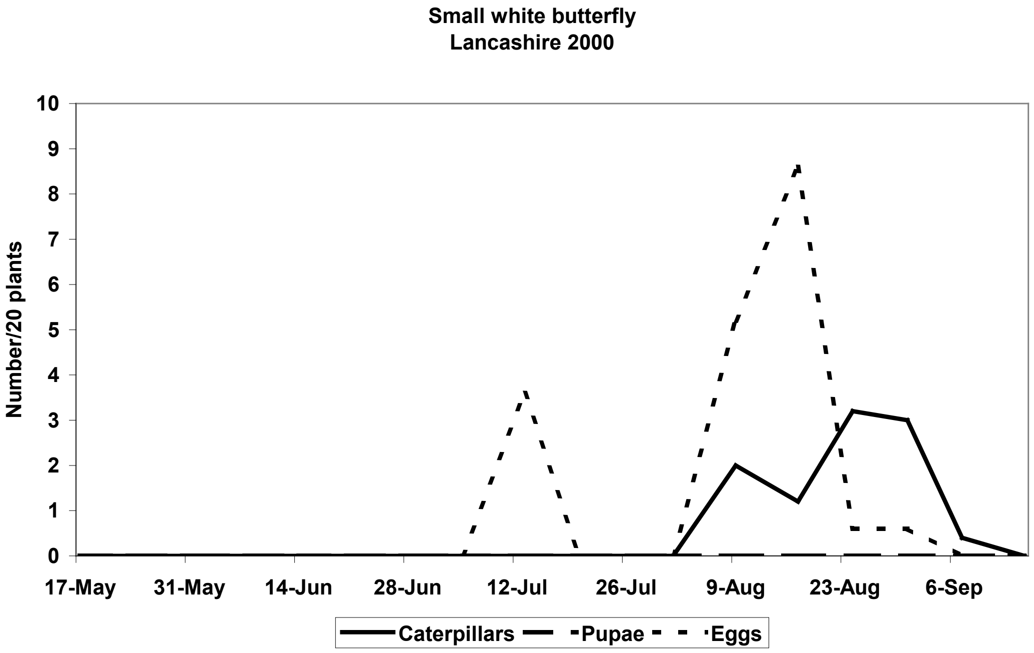
Appendix 4 The numbers of small white butterflies sampled in 2000

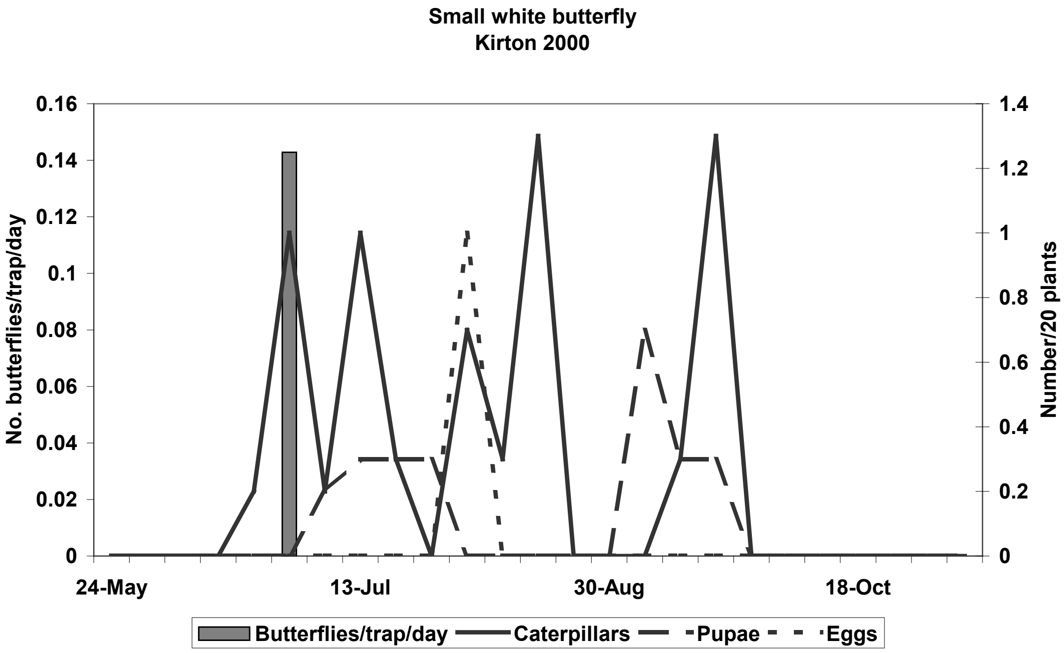




© 2001 Horticultural Development Council

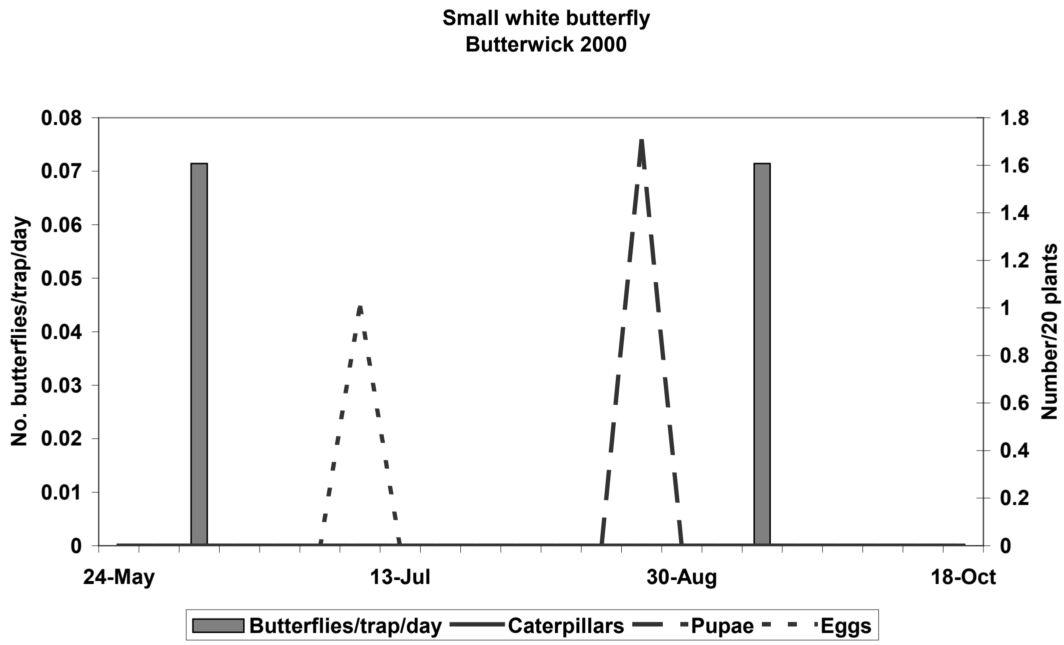
Appendix 4 The numbers of small white butterflies sampled in 2000

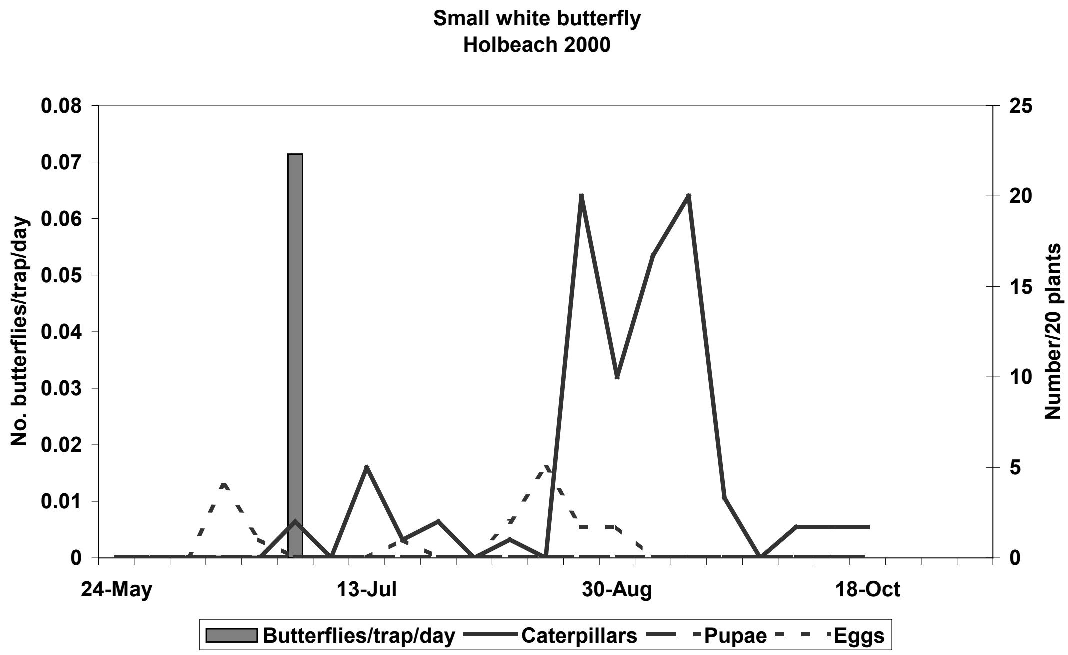




© 2001 Horticultural Development Council

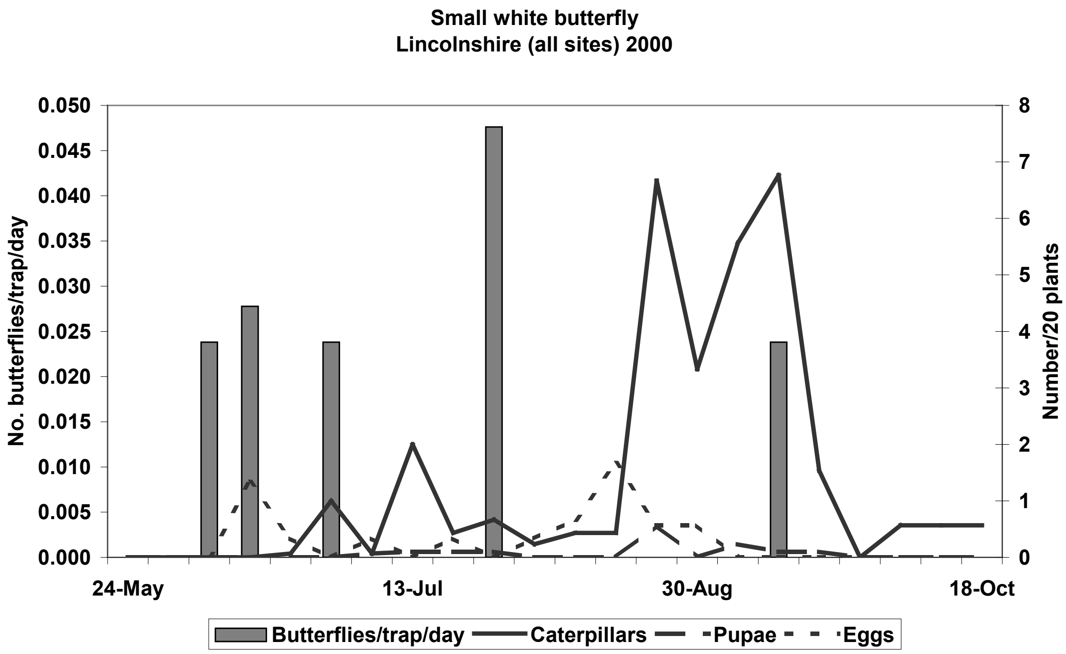
Appendix 4 The numbers of small white butterflies sampled in 2000





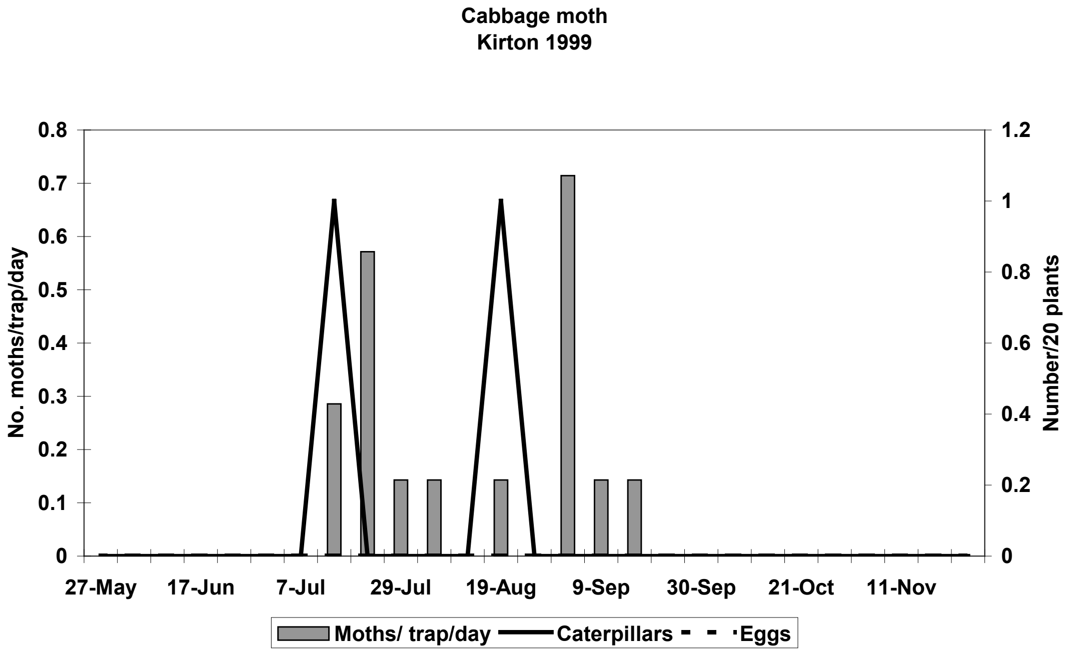
© 2001 Horticultural Development Council

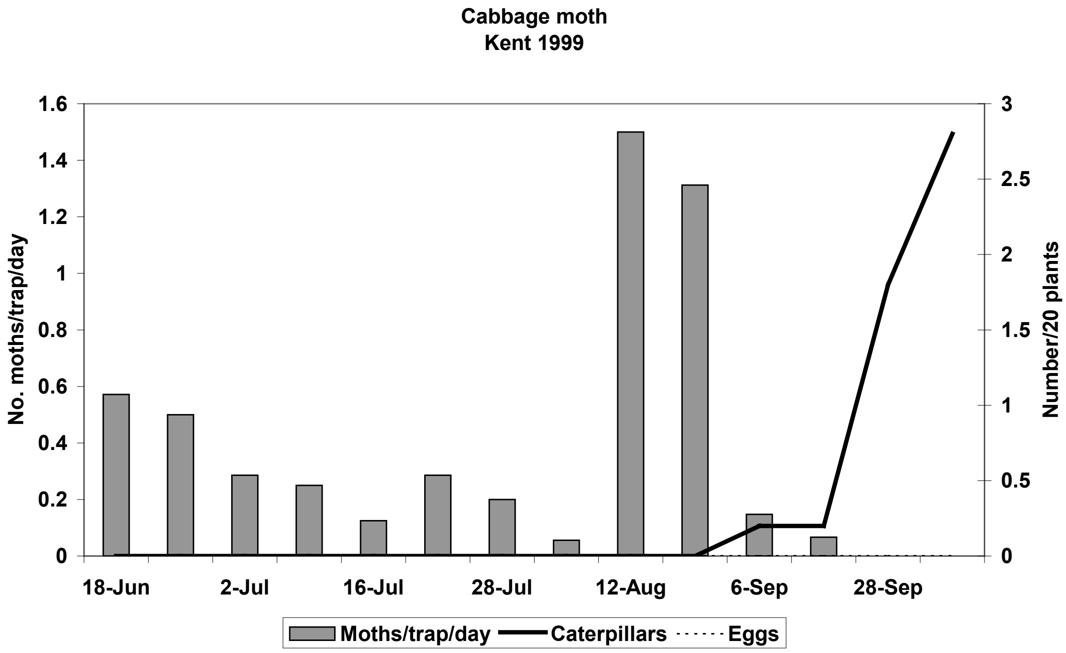
Appendix 4 The numbers of small white butterflies sampled in 2000



© 2001 Horticultural Development Council

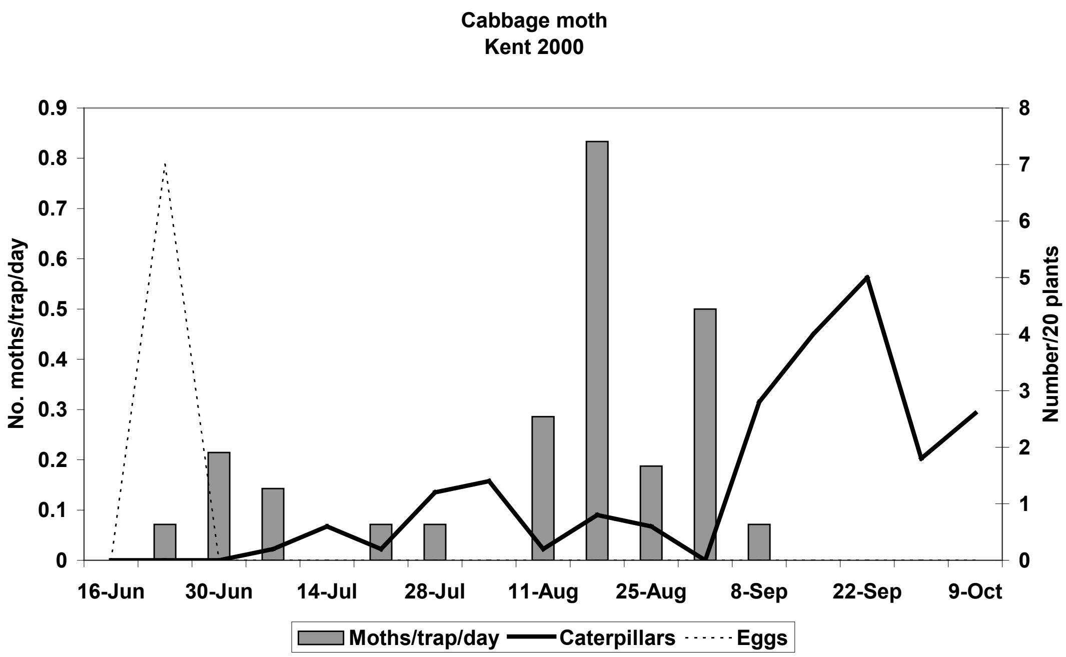
Appendix 5 The numbers of cabbage moths sampled in 1999.

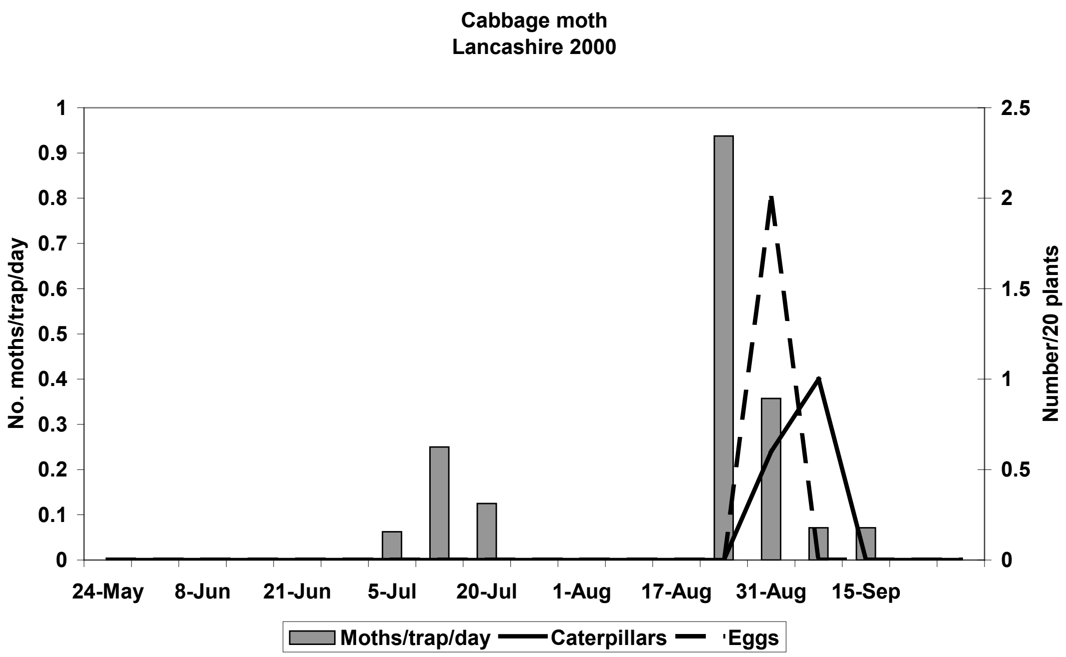




© 2001 Horticultural Development Council

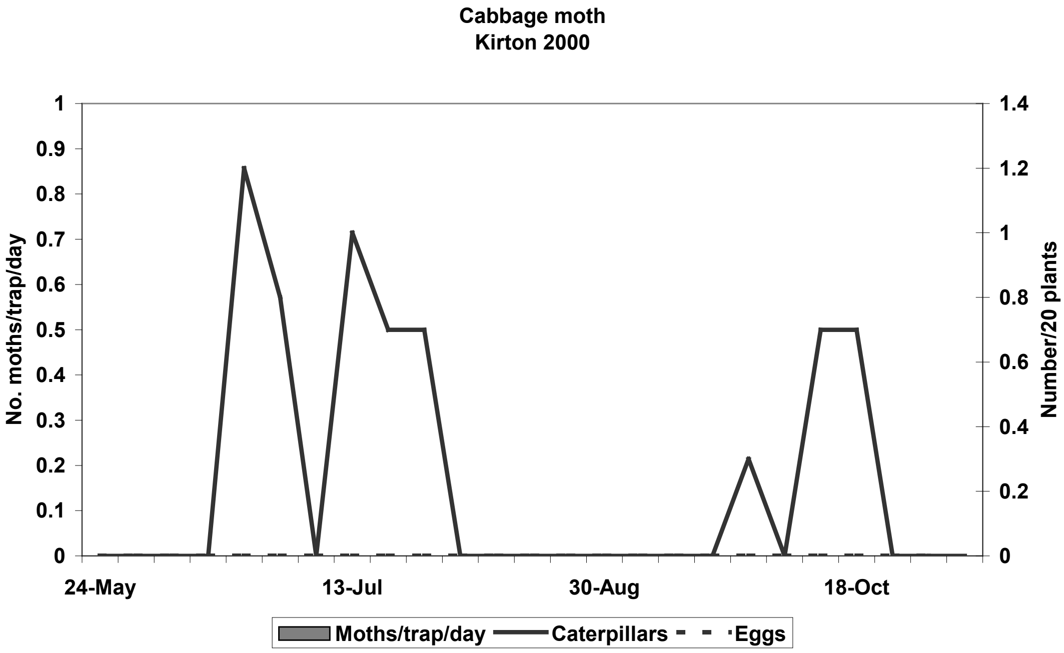
Appendix 6 The numbers of cabbage moths sampled in 2000.

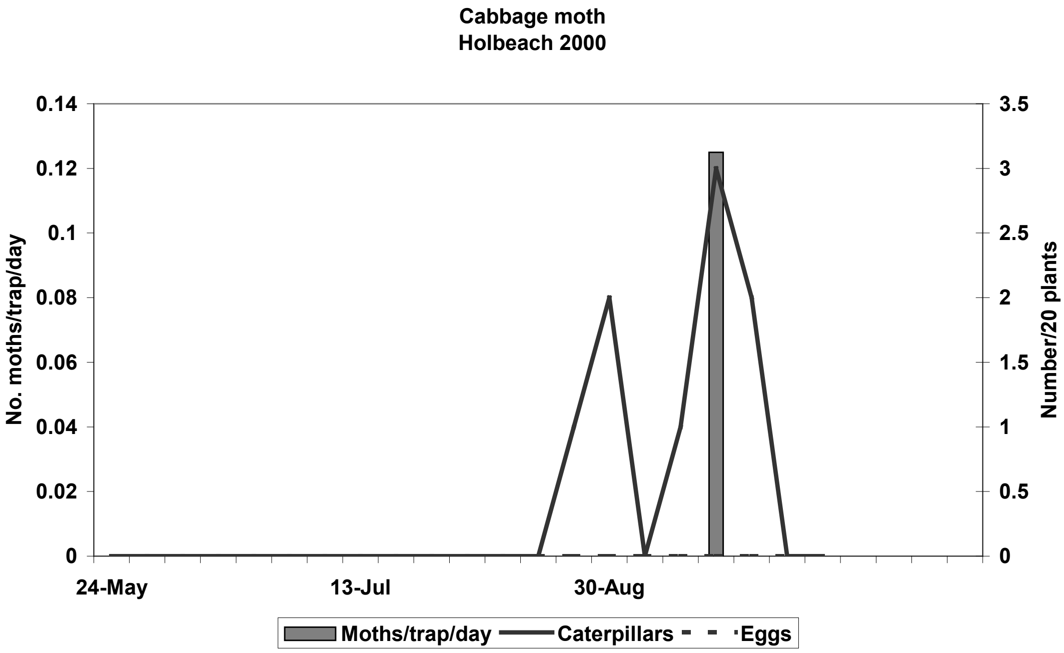




© 2001 Horticultural Development Council

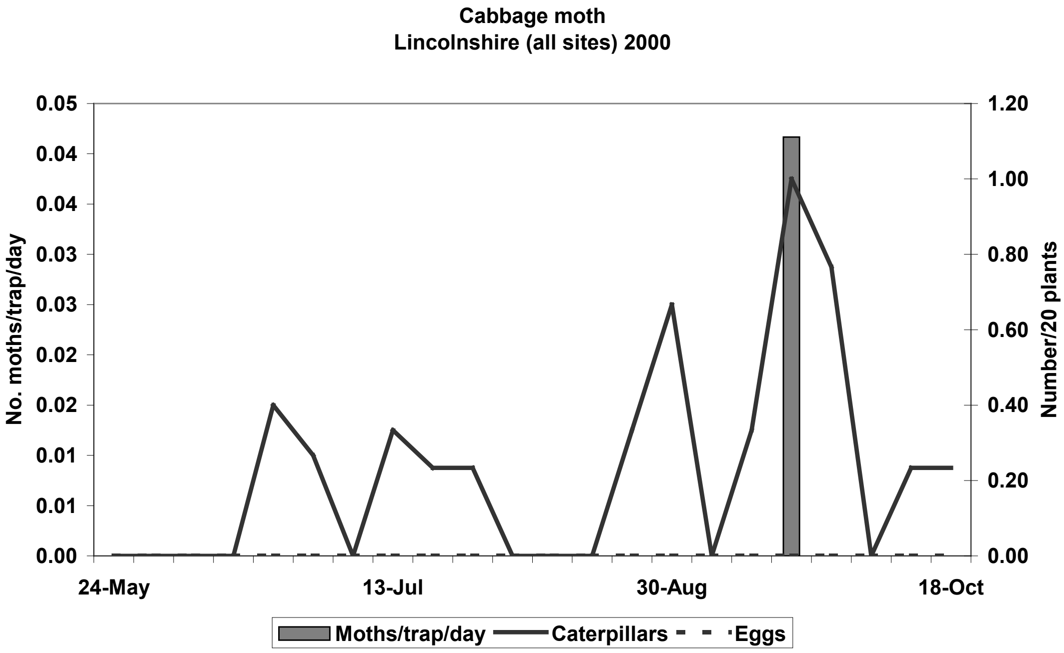
Appendix 6 The numbers of cabbage moths sampled in 2000.





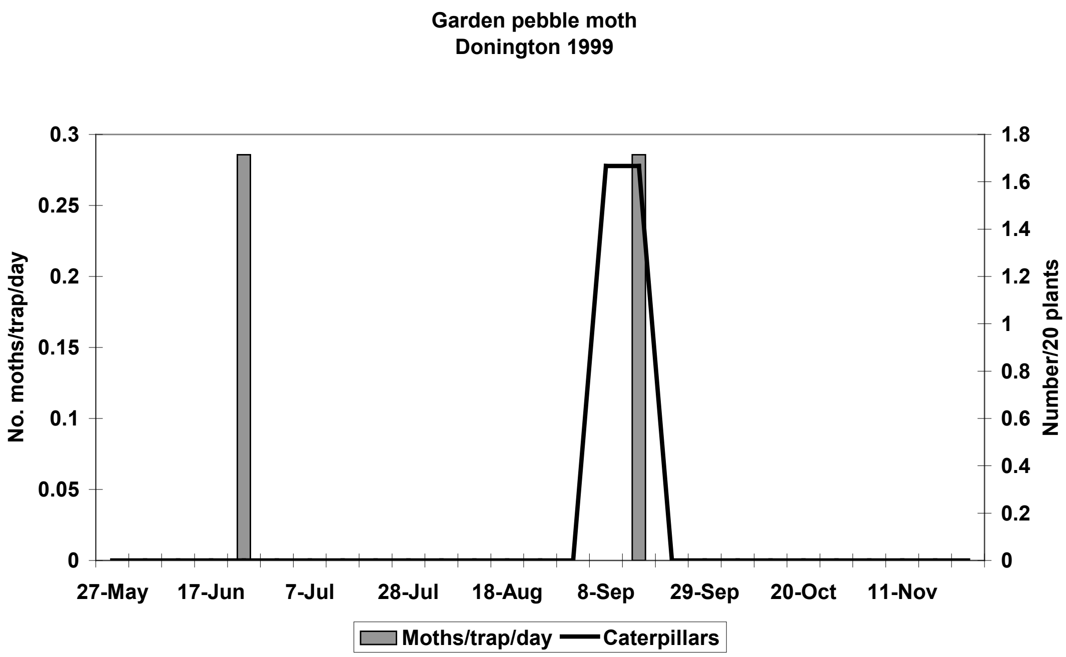
© 2001 Horticultural Development Council

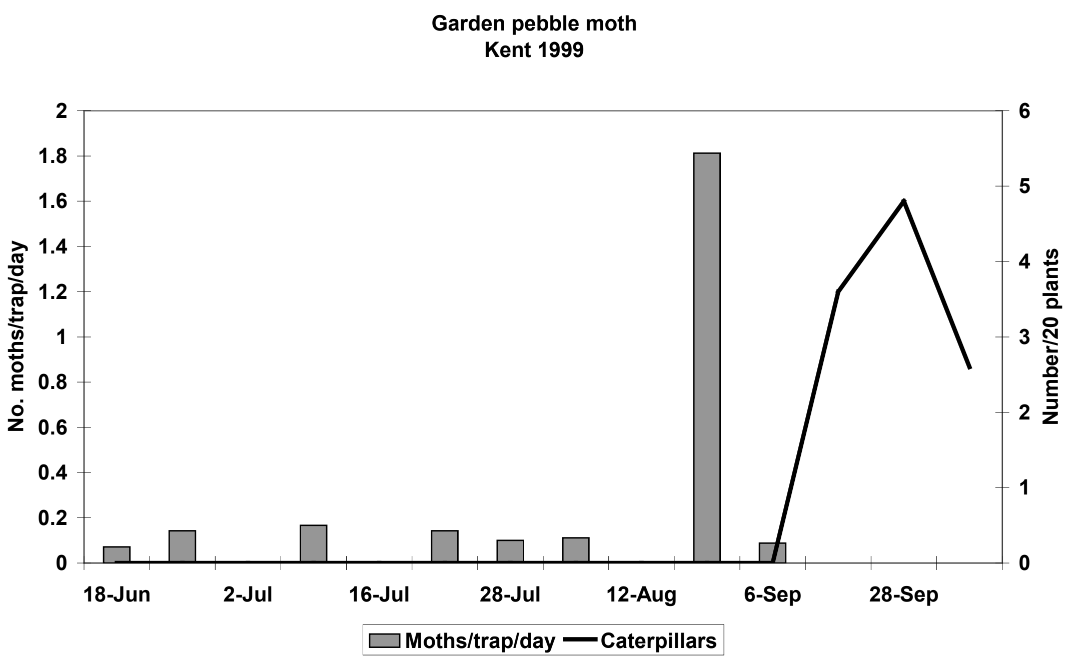
Appendix 6 The numbers of cabbage moths sampled in 2000.



© 2001 Horticultural Development Council

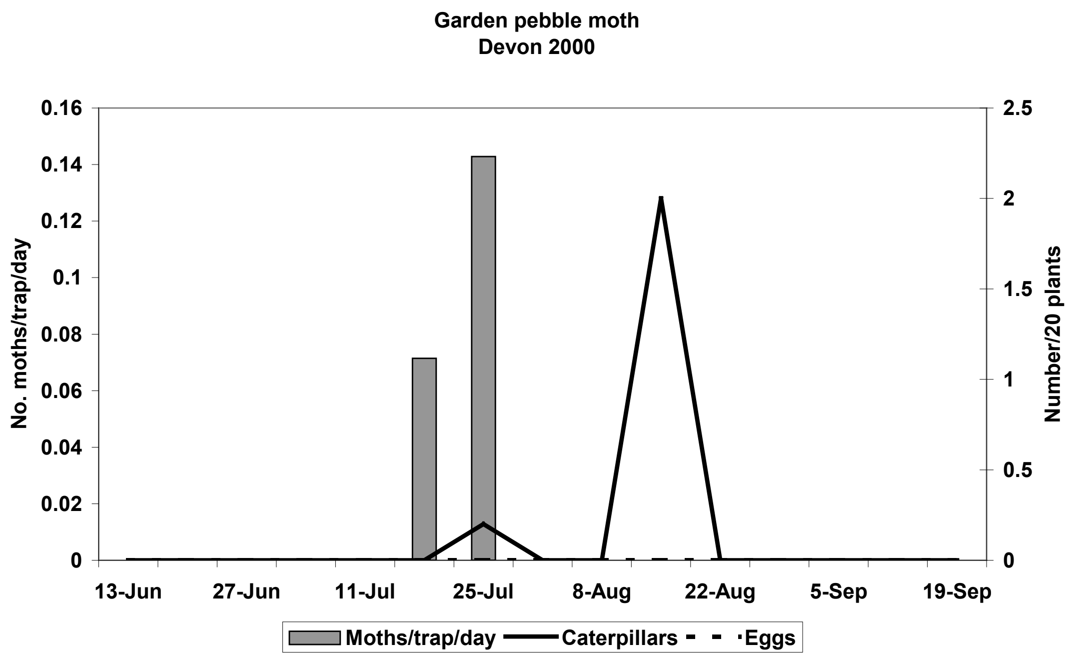
Appendix 7 The numbers of garden pebble moths sampled in 1999.

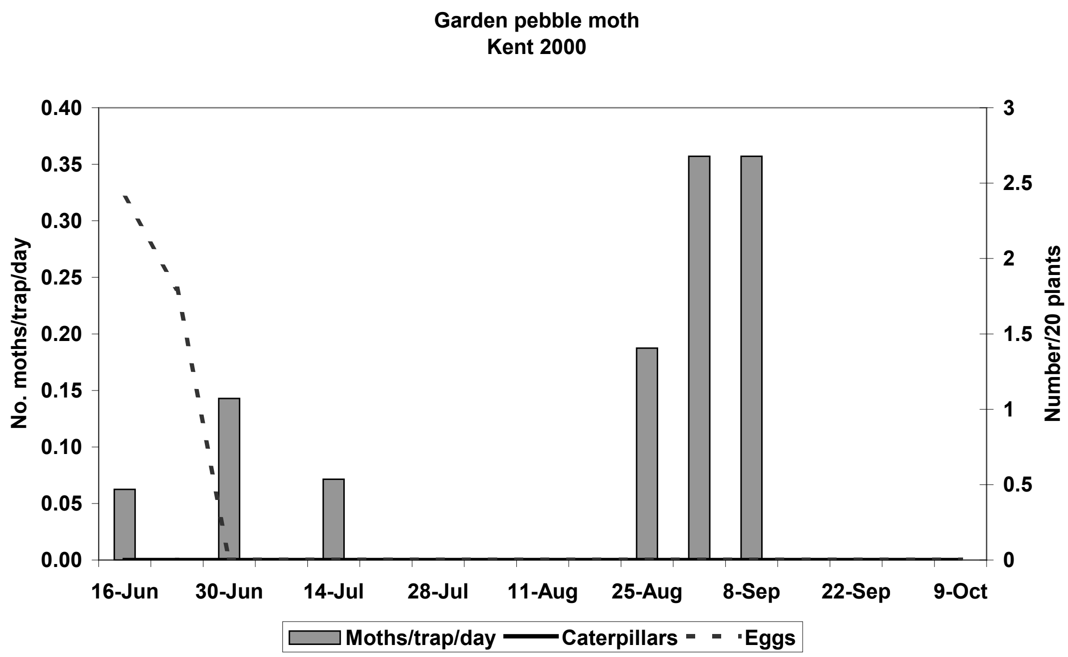




© 2001 Horticultural Development Council

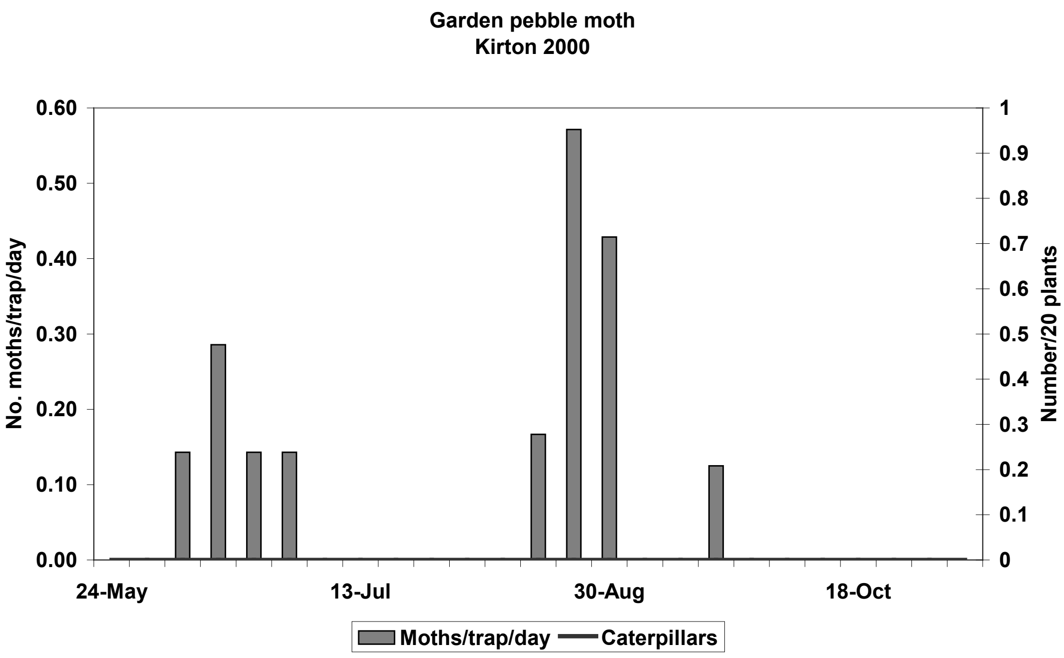
Appendix 8 The numbers of garden pebble moths sampled in 2000.

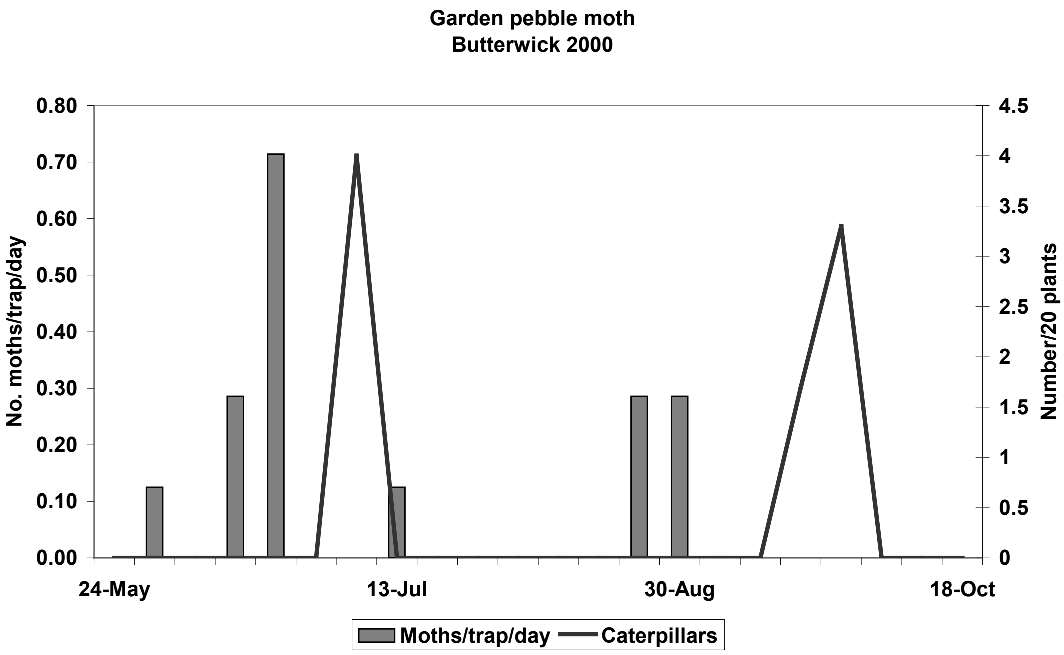




© 2001 Horticultural Development Council

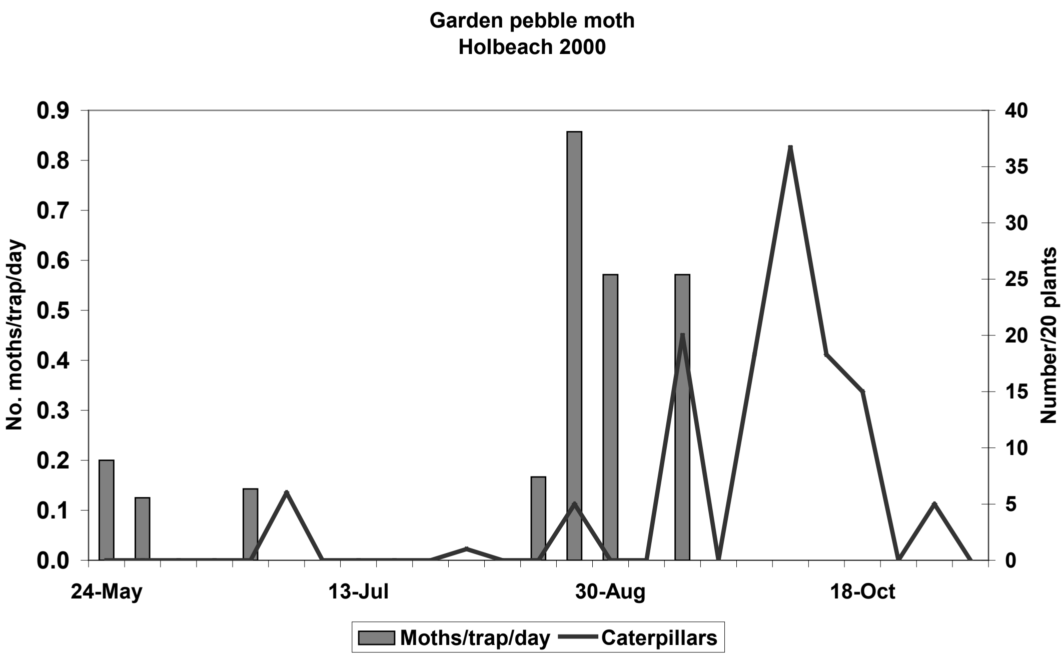
Appendix 8 The numbers of garden pebble moths sampled in 2000.

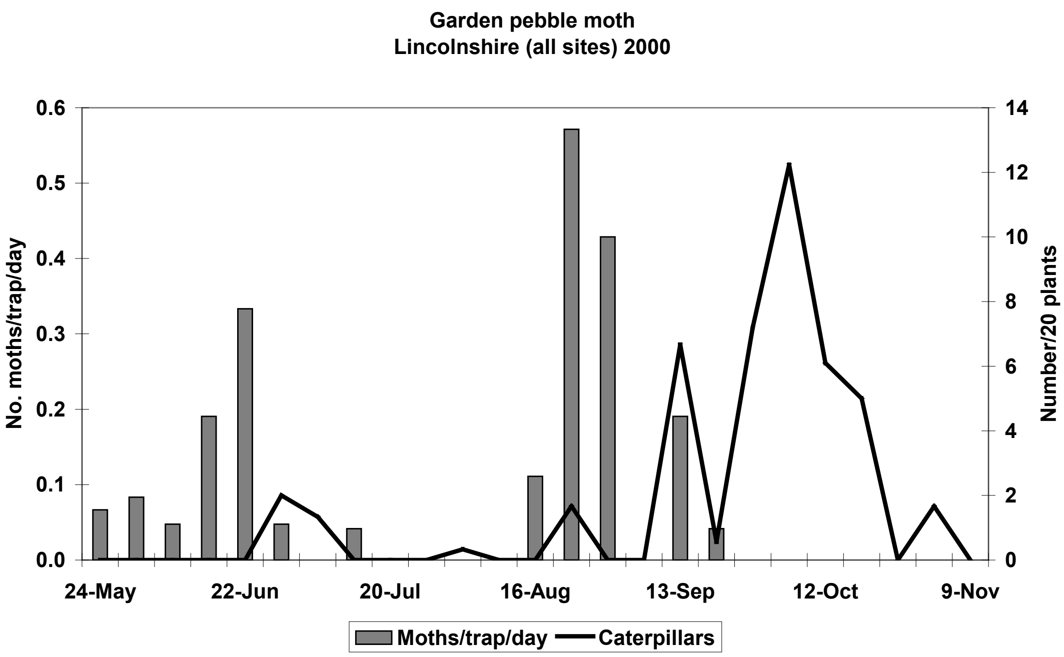




© 2001 Horticultural Development Council

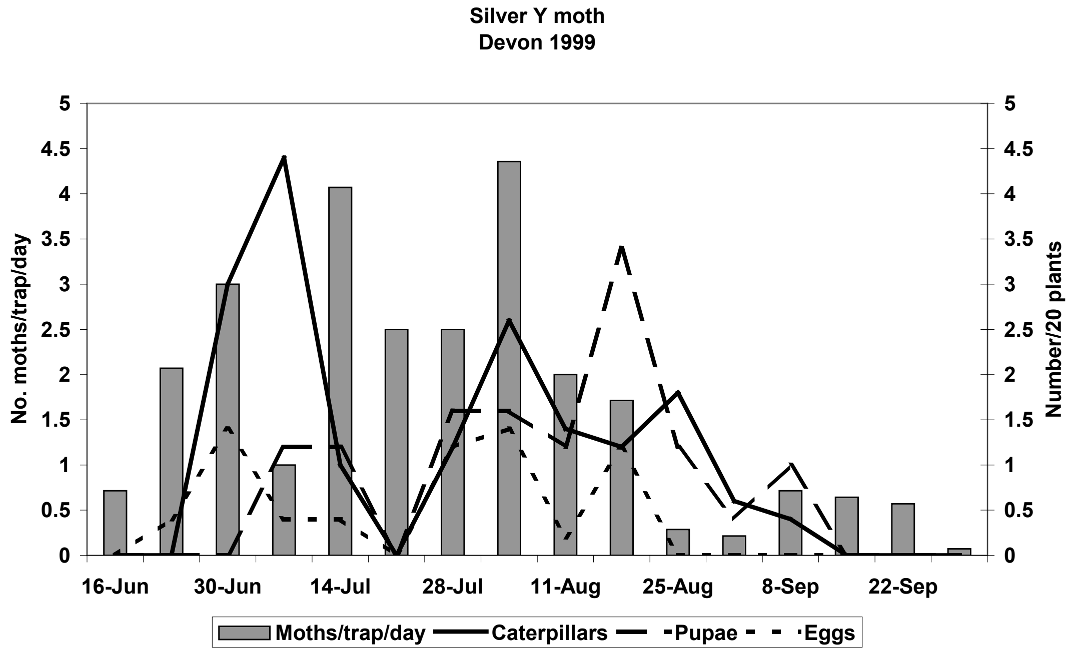
Appendix 8 The numbers of garden pebble moths sampled in 2000.

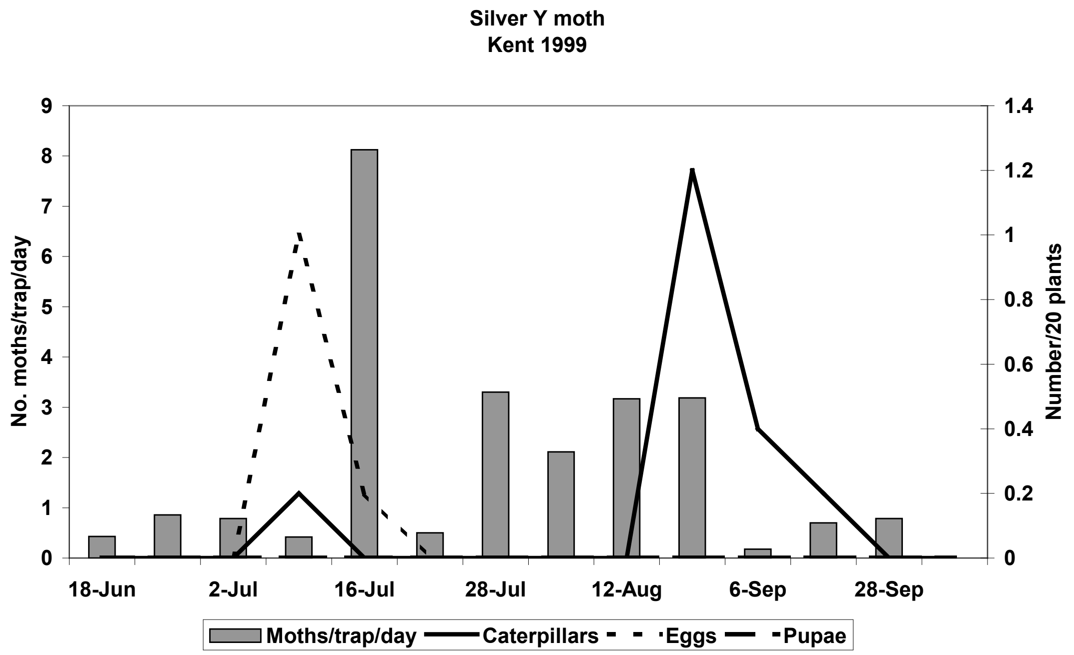




© 2001 Horticultural Development Council

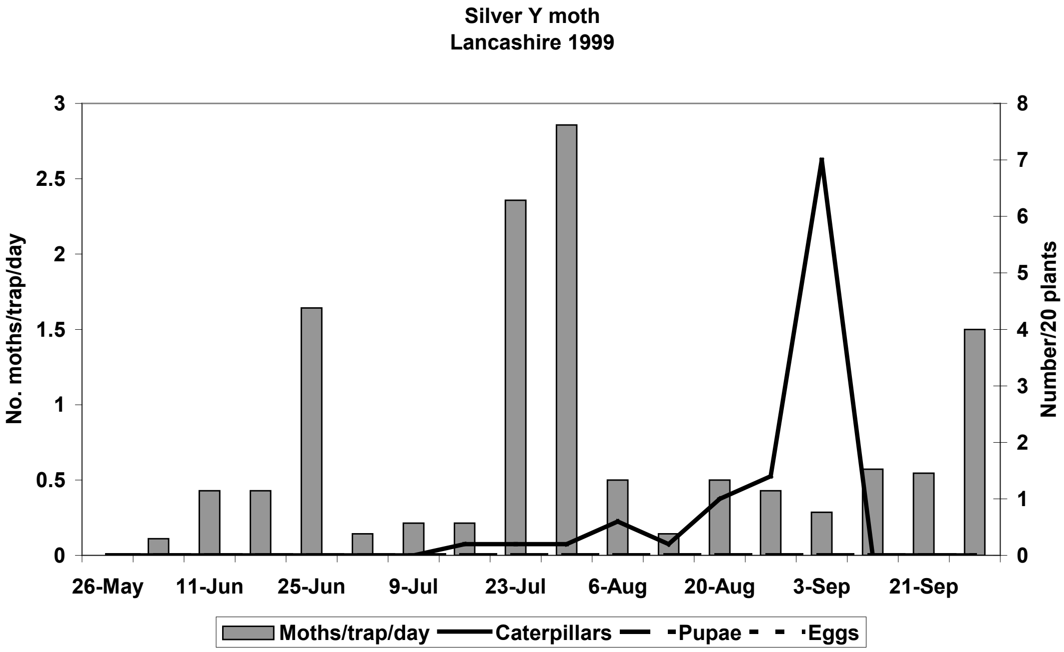
Appendix 9 The numbers of silver Y moths sampled in 1999.

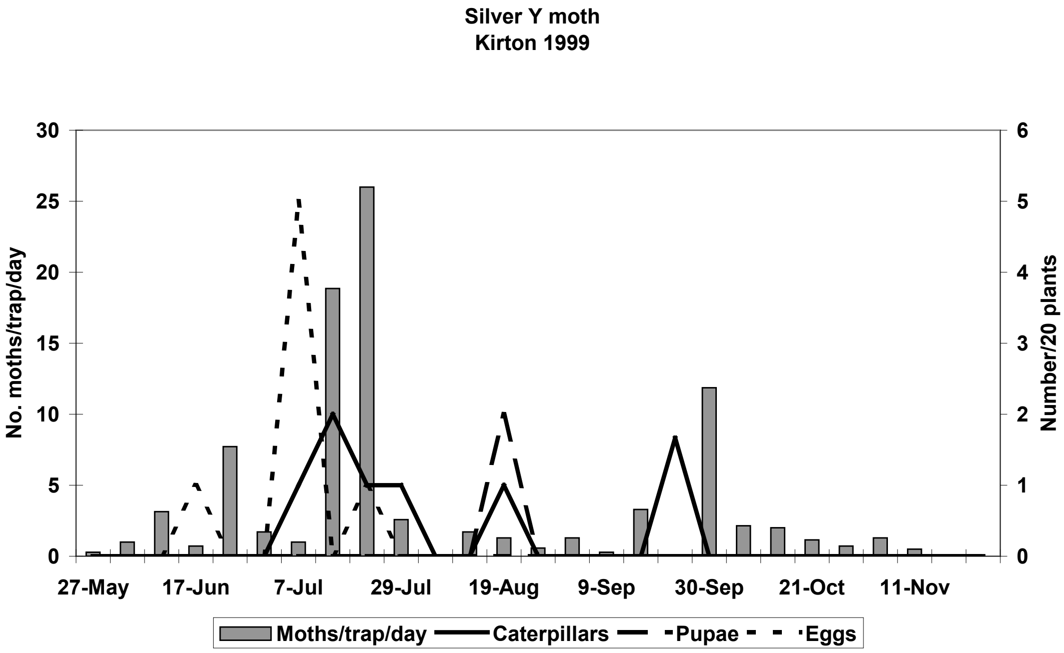




© 2001 Horticultural Development Council

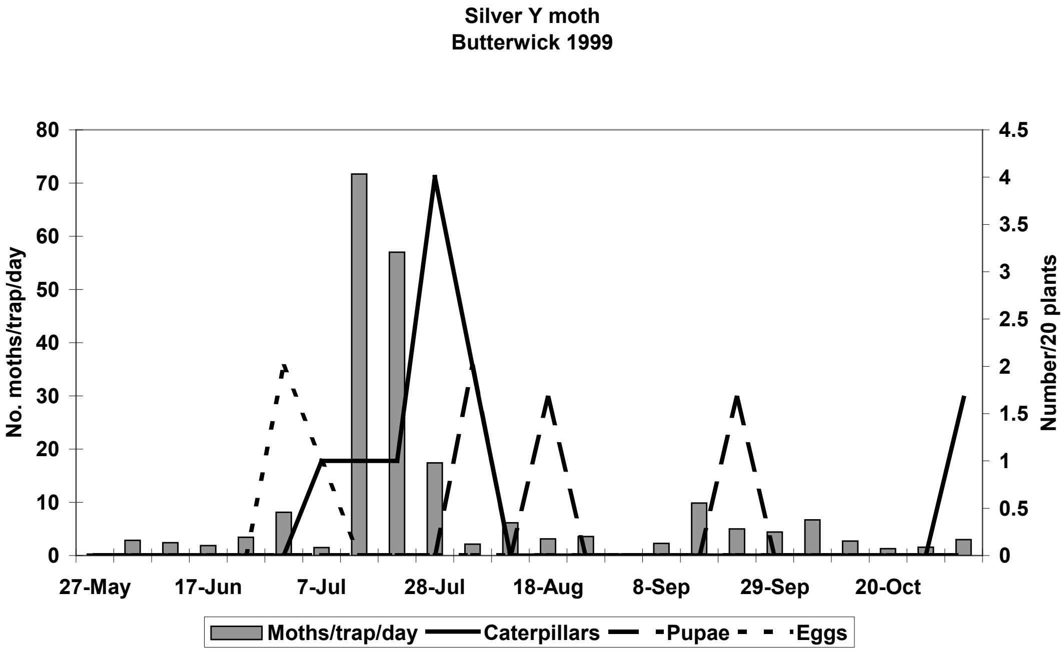
Appendix 9 The numbers of silver Y moths sampled in 1999.

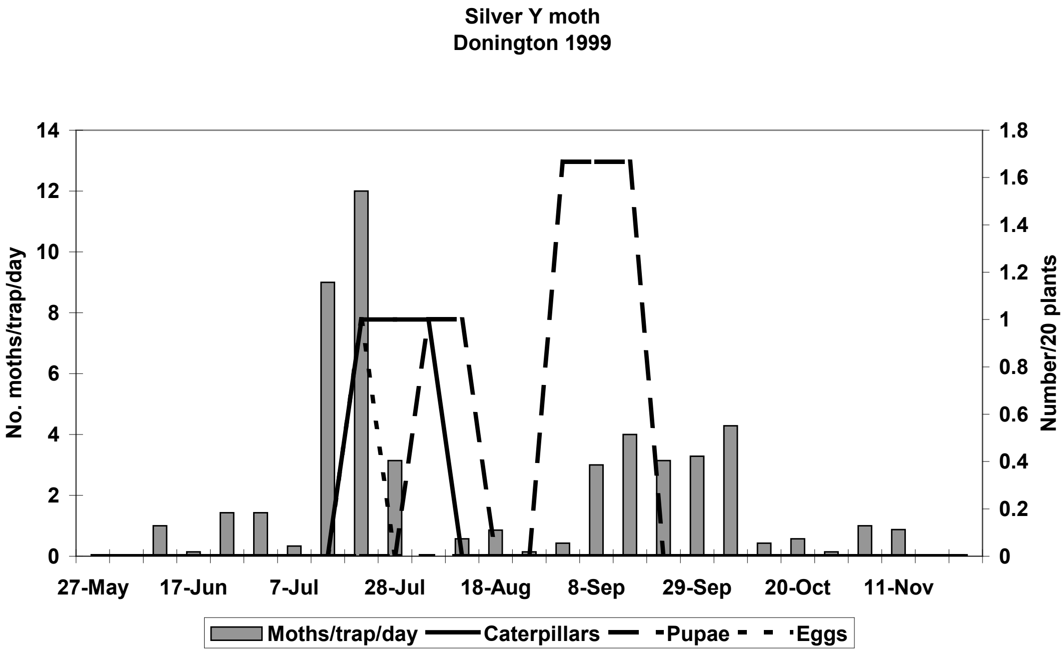




© 2001 Horticultural Development Council

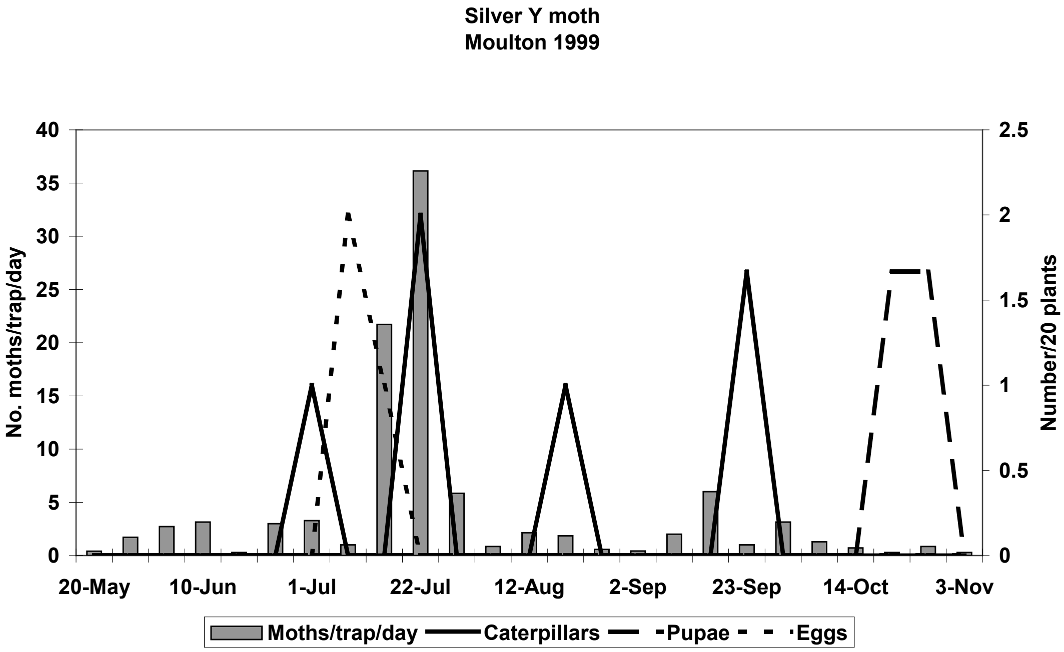
Appendix 9 The numbers of silver Y moths sampled in 1999.

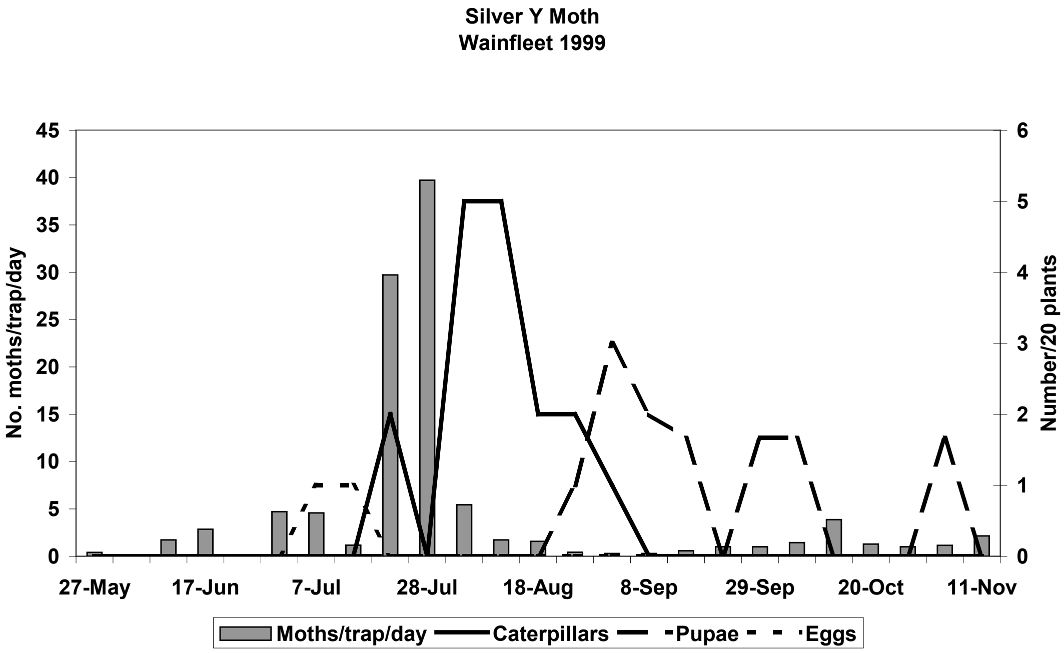




© 2001 Horticultural Development Council

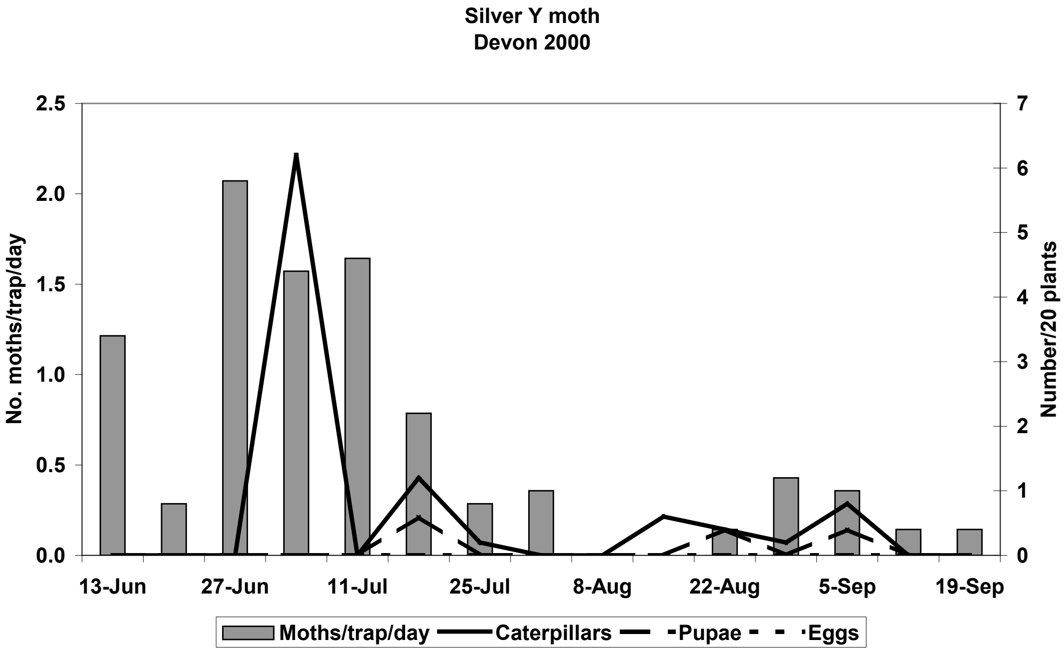
Appendix 9 The numbers of silver Y moths sampled in 1999.

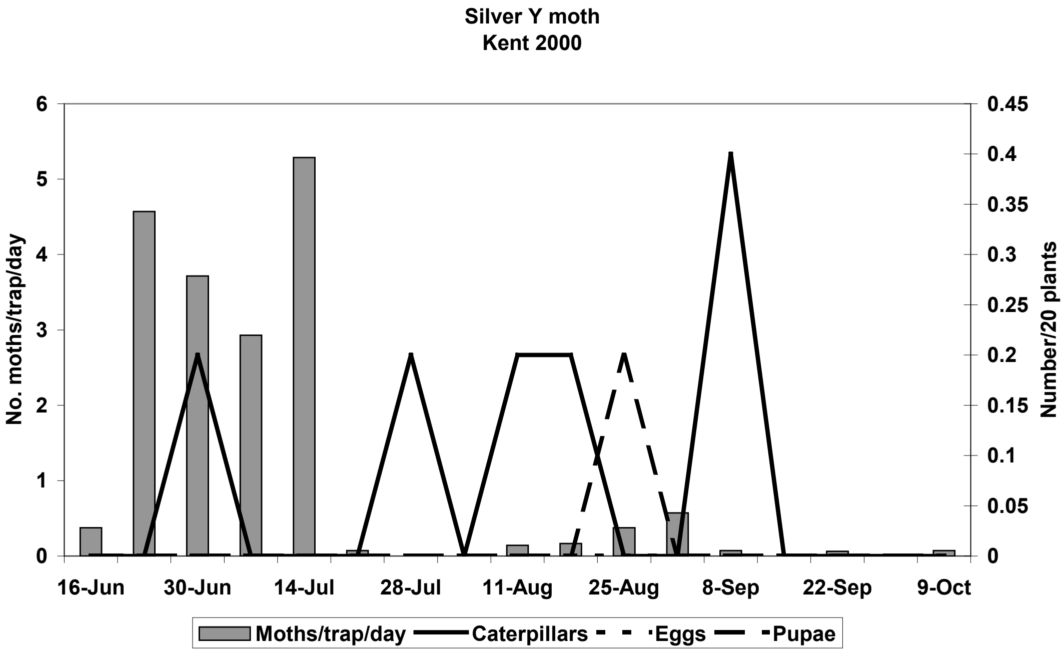




© 2001 Horticultural Development Council

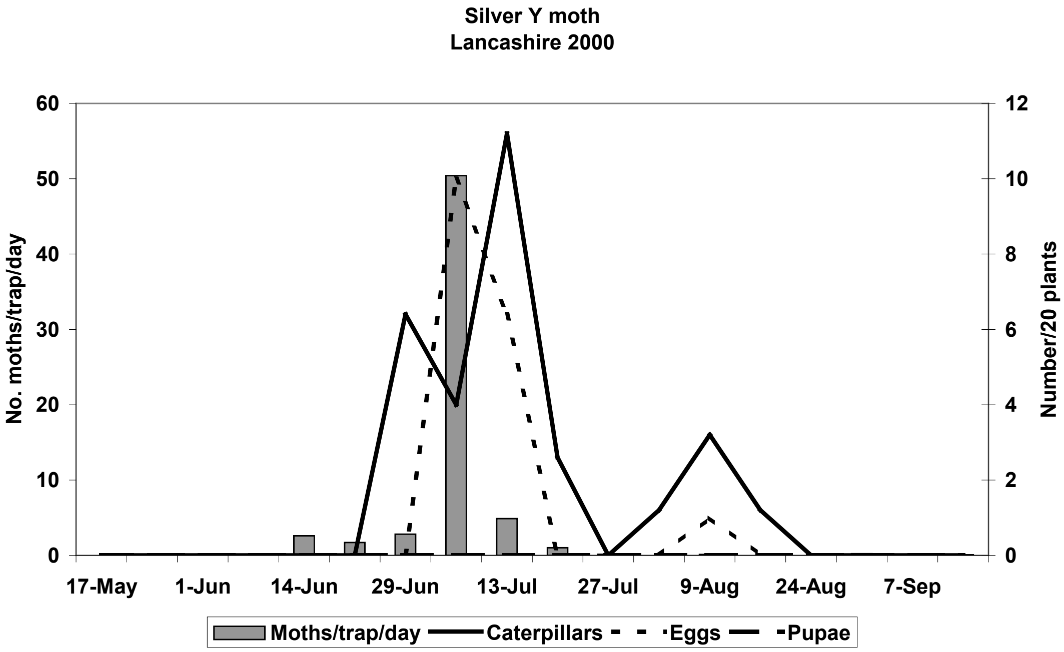
Appendix 10 The numbers of silver Y moths sampled in 2000.

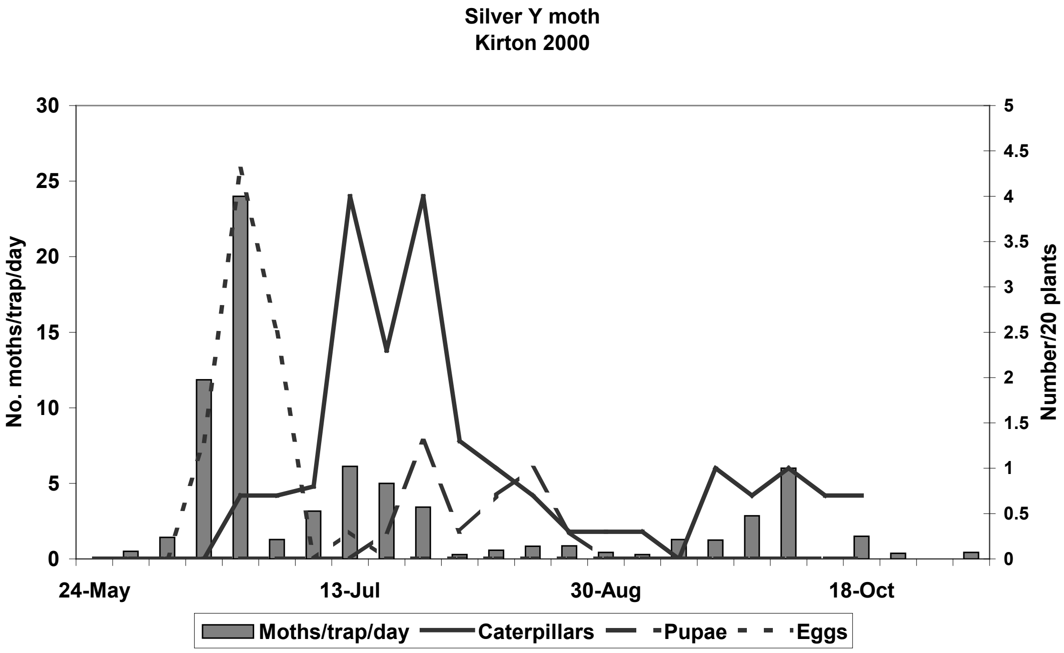




© 2001 Horticultural Development Council

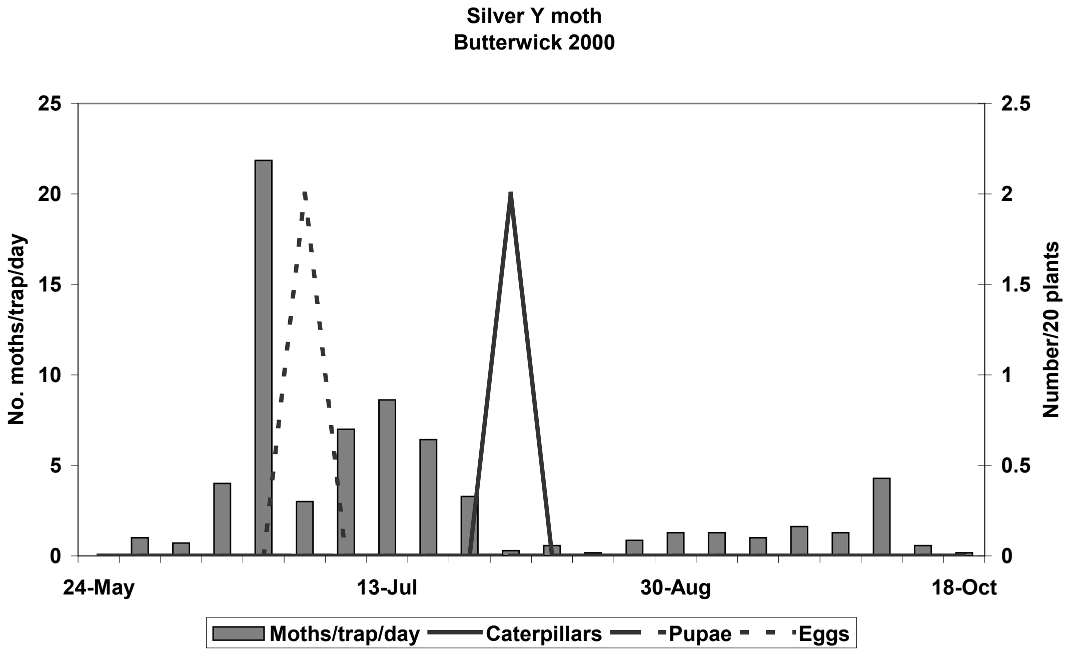
Appendix 10 The numbers of silver Y moths sampled in 2000.

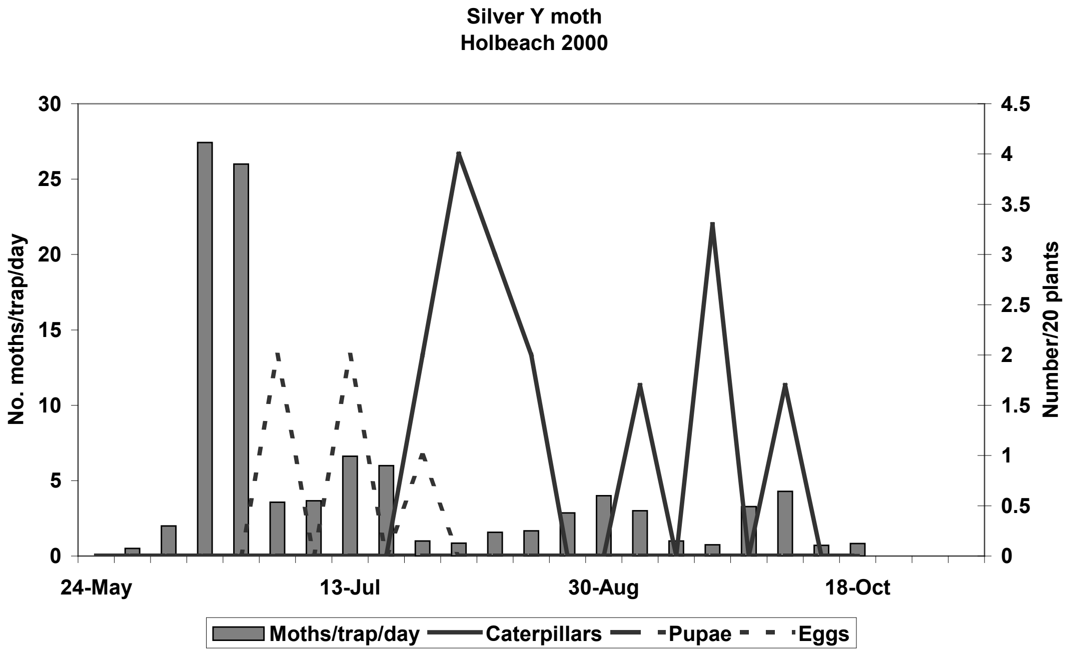




© 2001 Horticultural Development Council

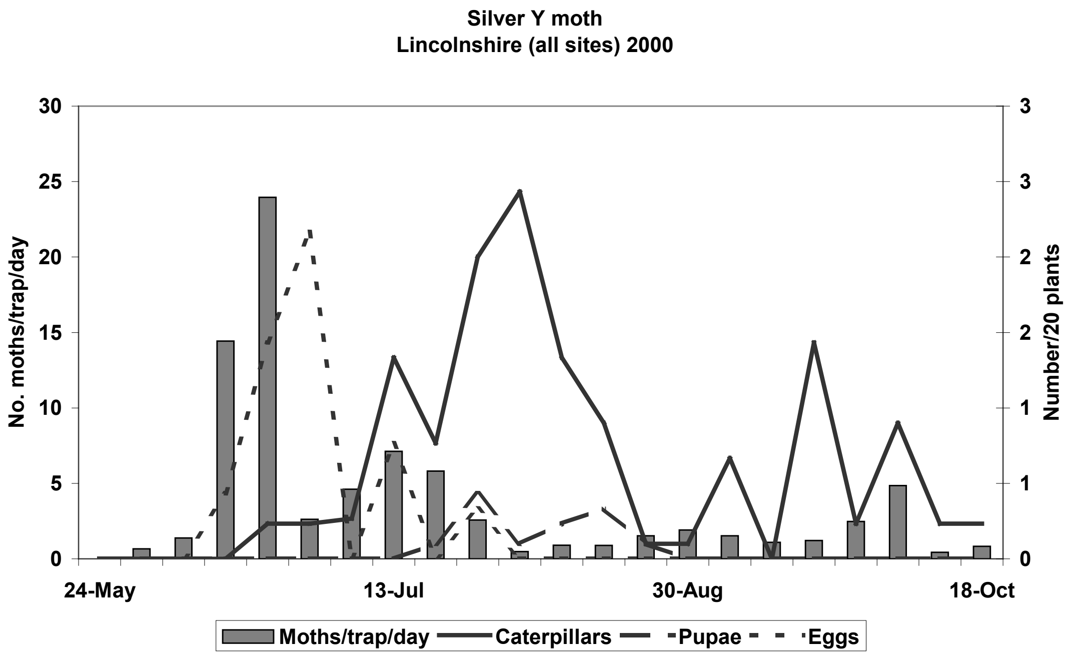
Appendix 10 The numbers of silver Y moths sampled in 2000.





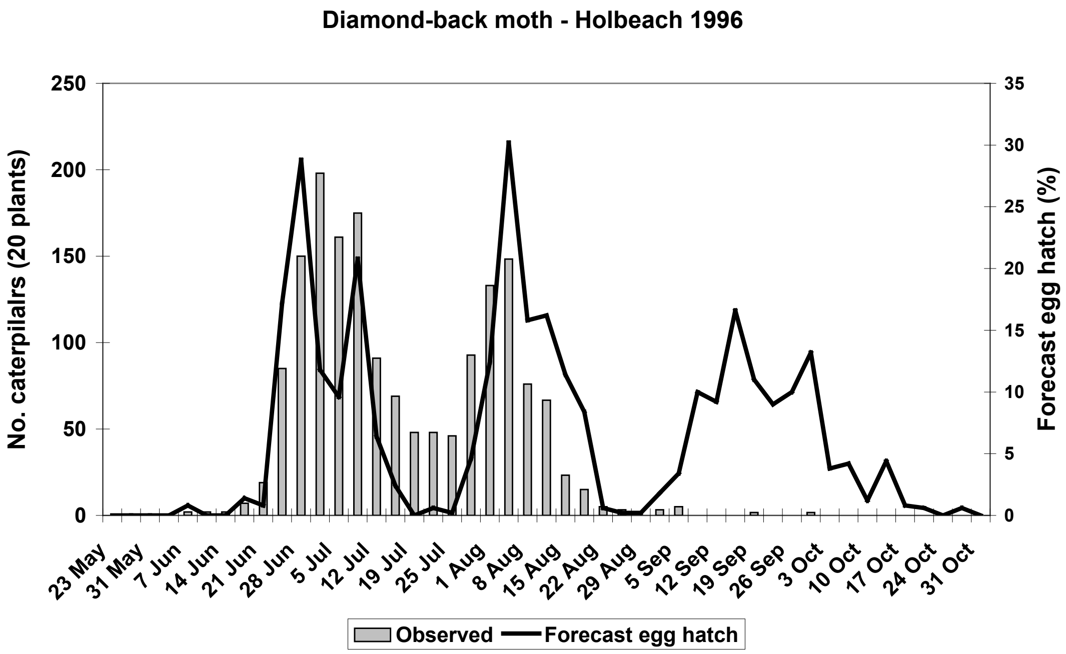
© 2001 Horticultural Development Council

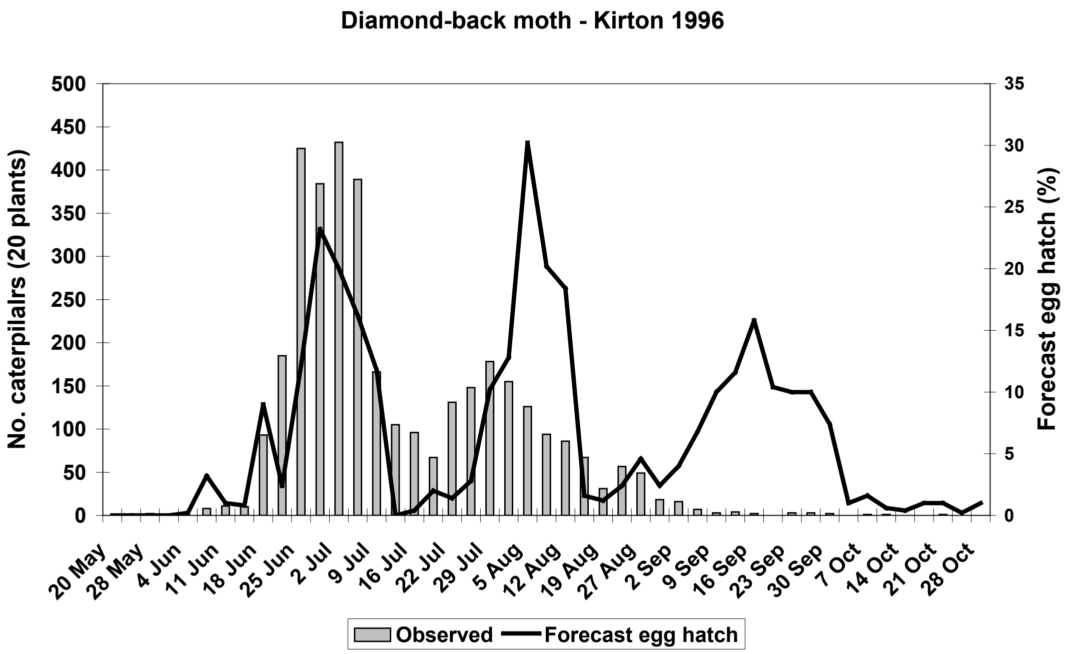
Appendix 10 The numbers of silver Y moths sampled in 2000.



© 2001 Horticultural Development Council

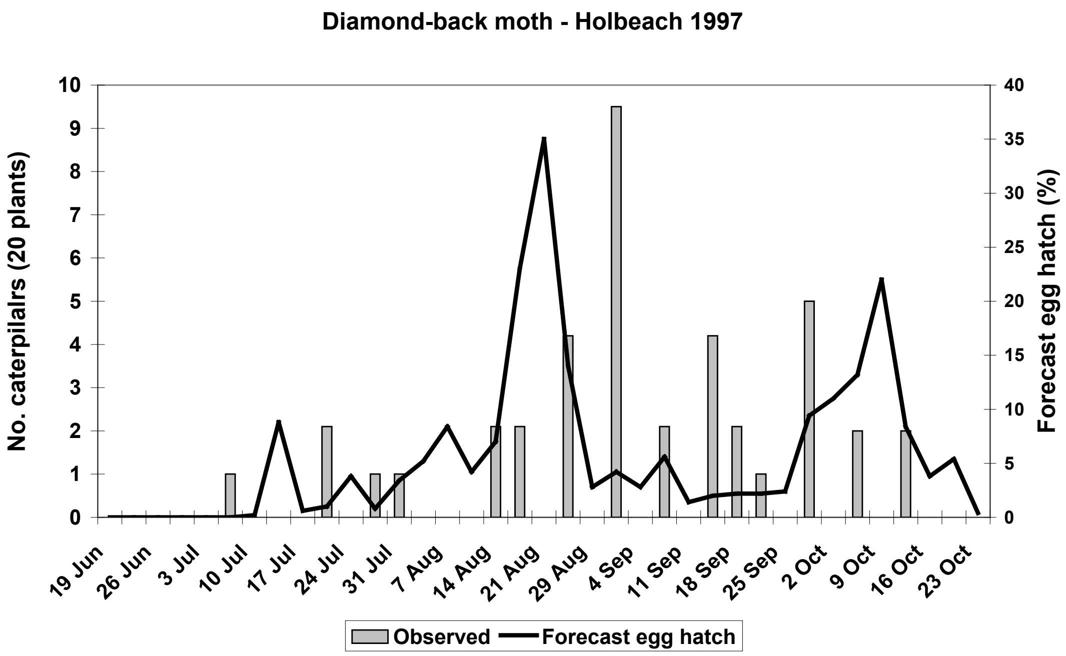
Appendix 11 Comparison of the numbers of diamond-back moth caterpillars found on untreated Brussels sprout plants with forecasts of egg hatch. The forecasts were generated using moth trap captures during the 'first' generation.

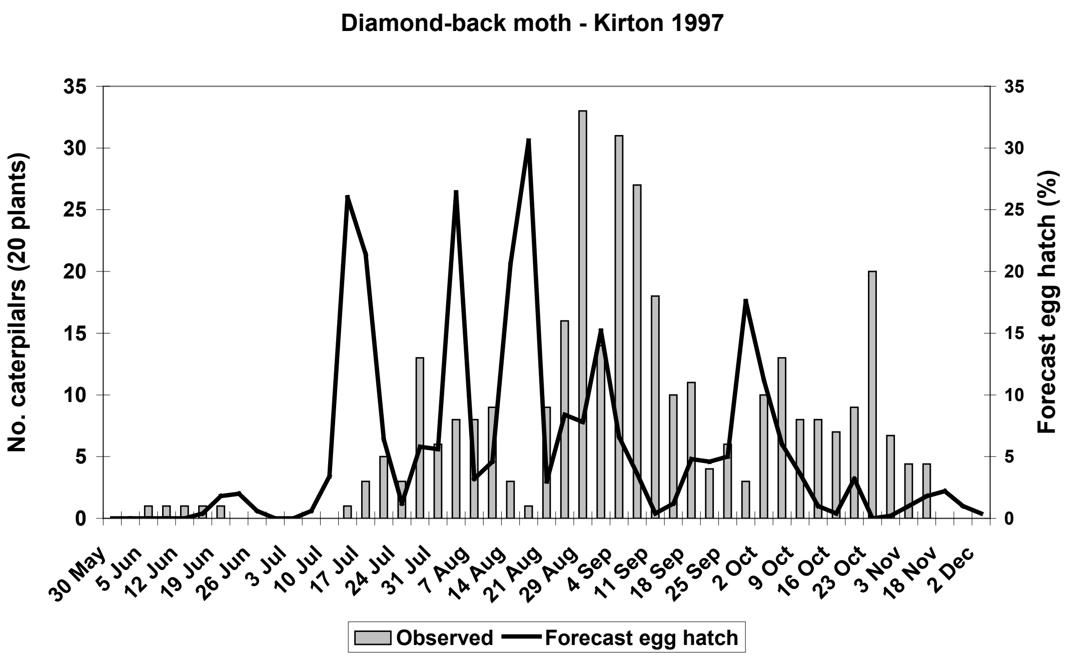




© 2001 Horticultural Development Council

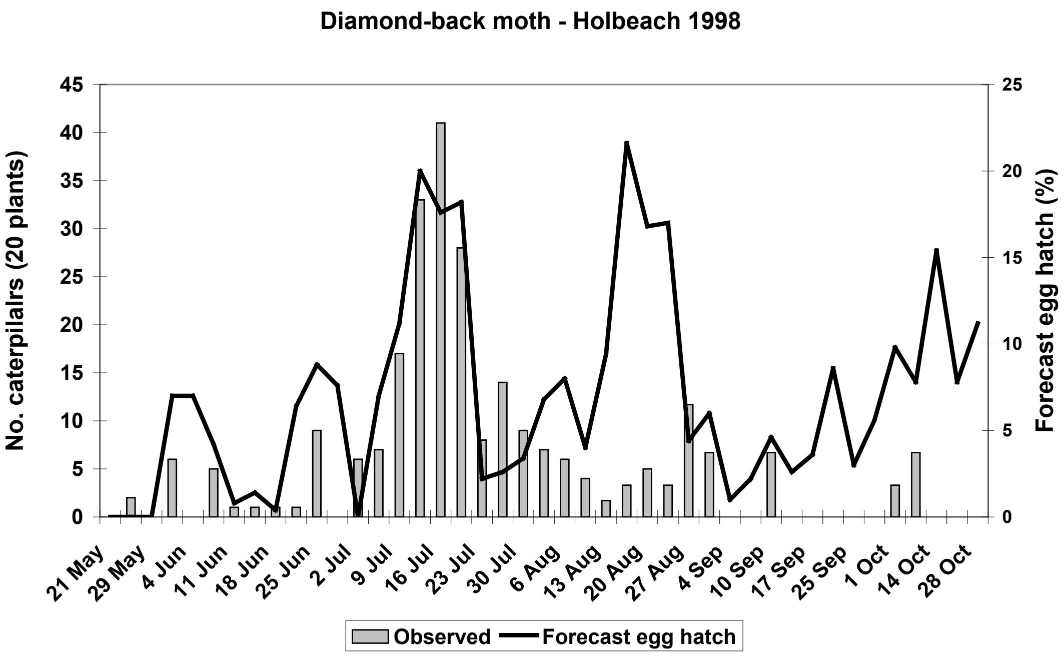
Appendix 11 Comparison of the numbers of diamond-back moth caterpillars found On untreated Brussels sprout plants with forecasts of egg hatch. The forecasts were generated using moth trap captures during the 'first' generation.

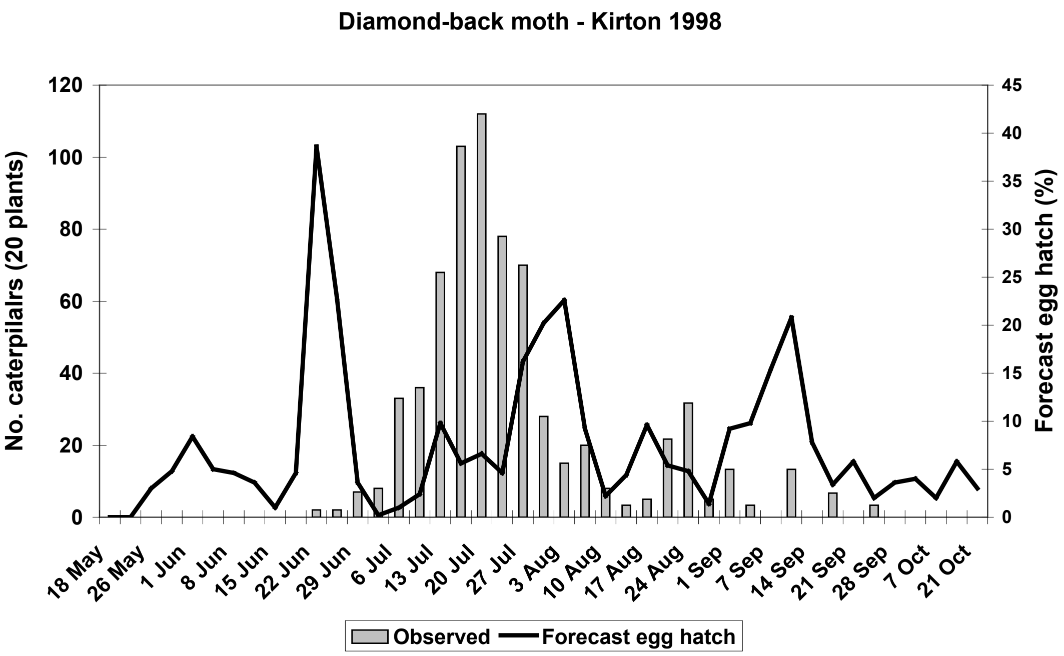




© 2001 Horticultural Development Council

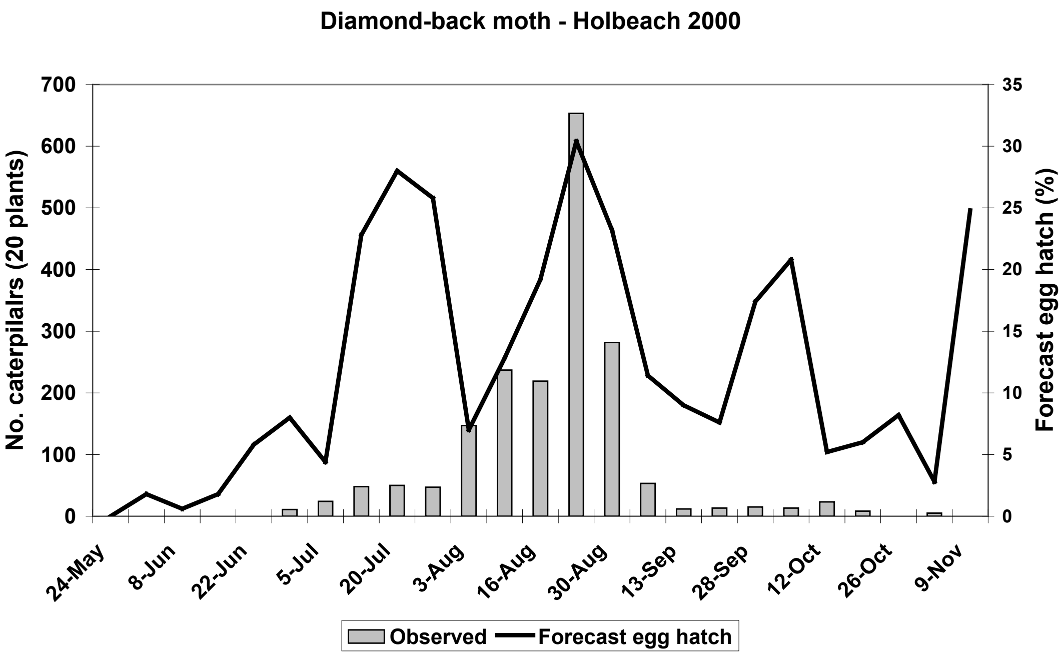
Appendix 11 Comparison of the numbers of diamond-back moth caterpillars found on untreated Brussels sprout plants with forecasts of egg hatch. The forecasts were generated using moth trap captures during the 'first' generation.

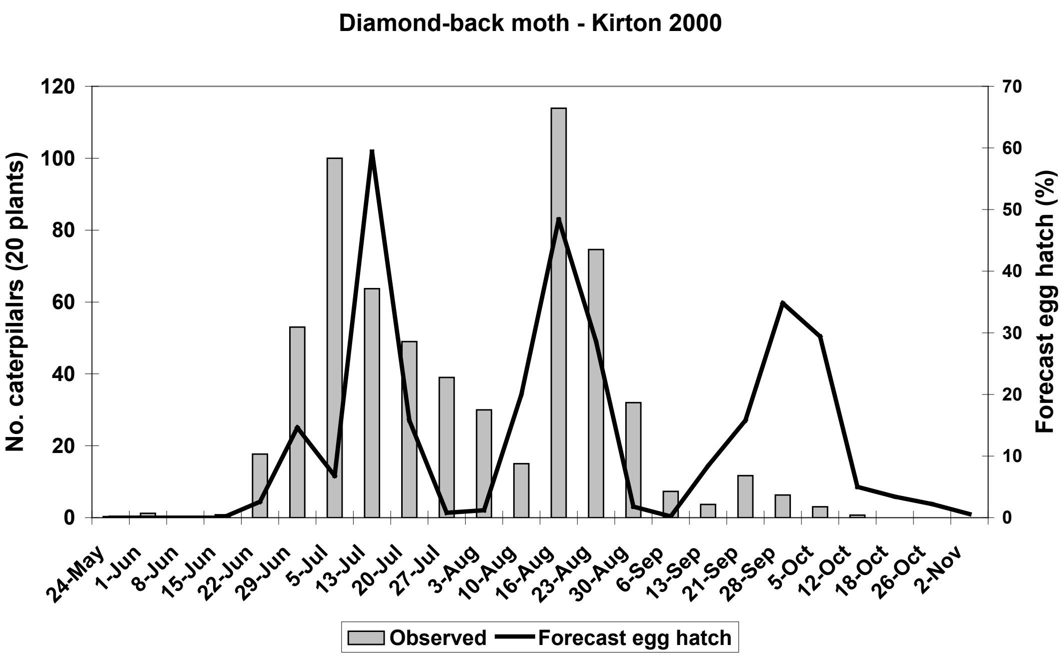




© 2001 Horticultural Development Council

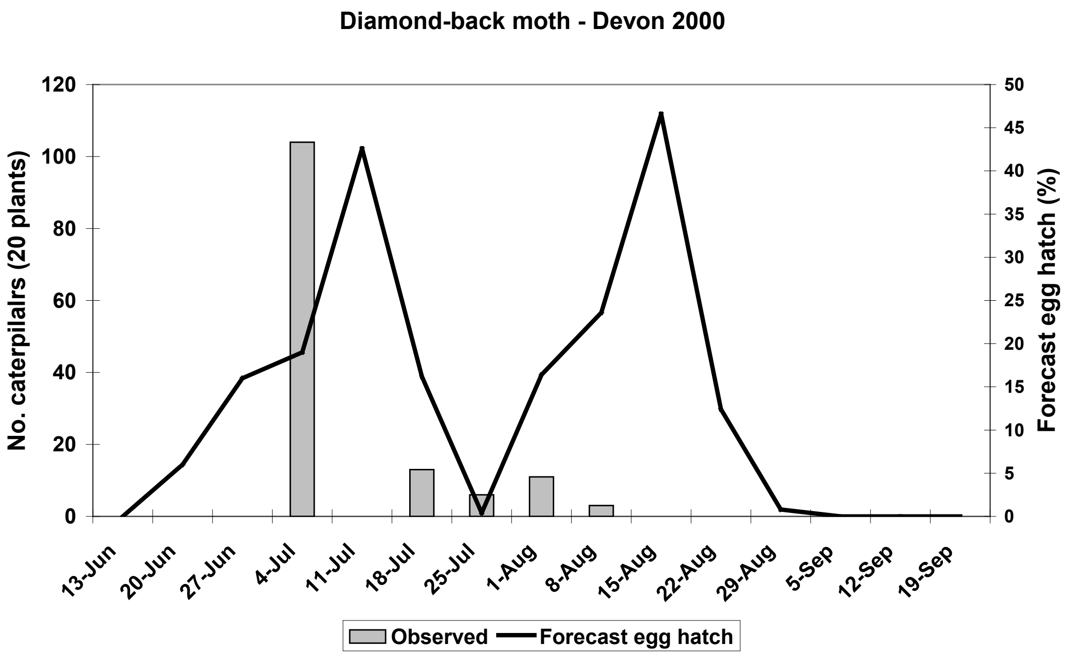
Appendix 11 Comparison of the numbers of diamond-back moth caterpillars found on untreated Brussels sprout plants with forecasts of egg hatch. The forecasts were generated using moth trap captures during the 'first' generation.

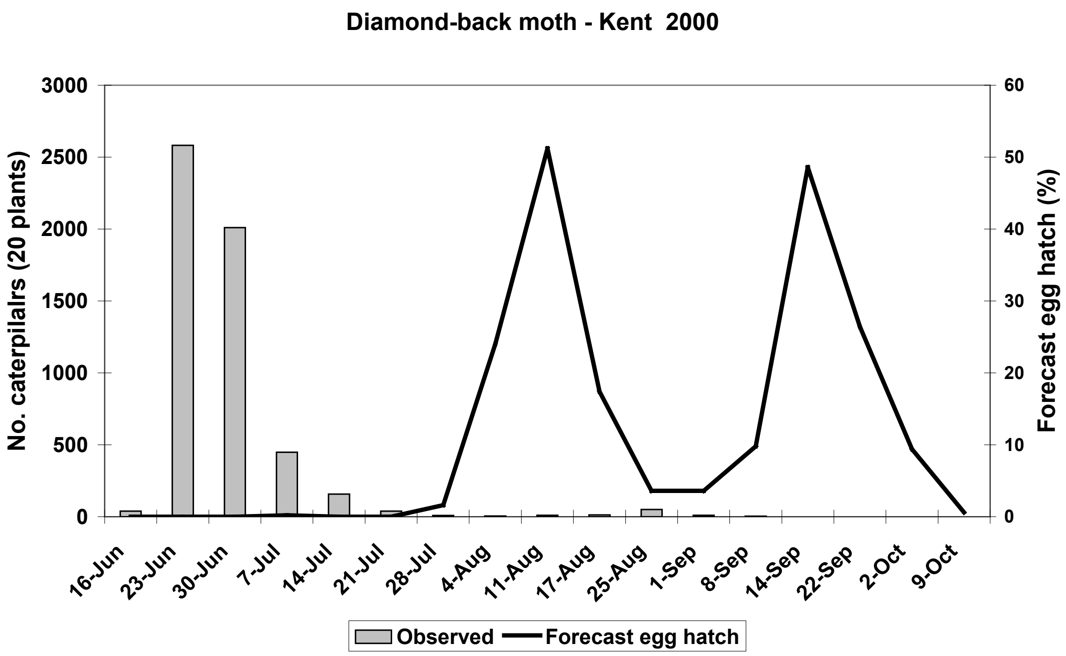




© 2001 Horticultural Development Council

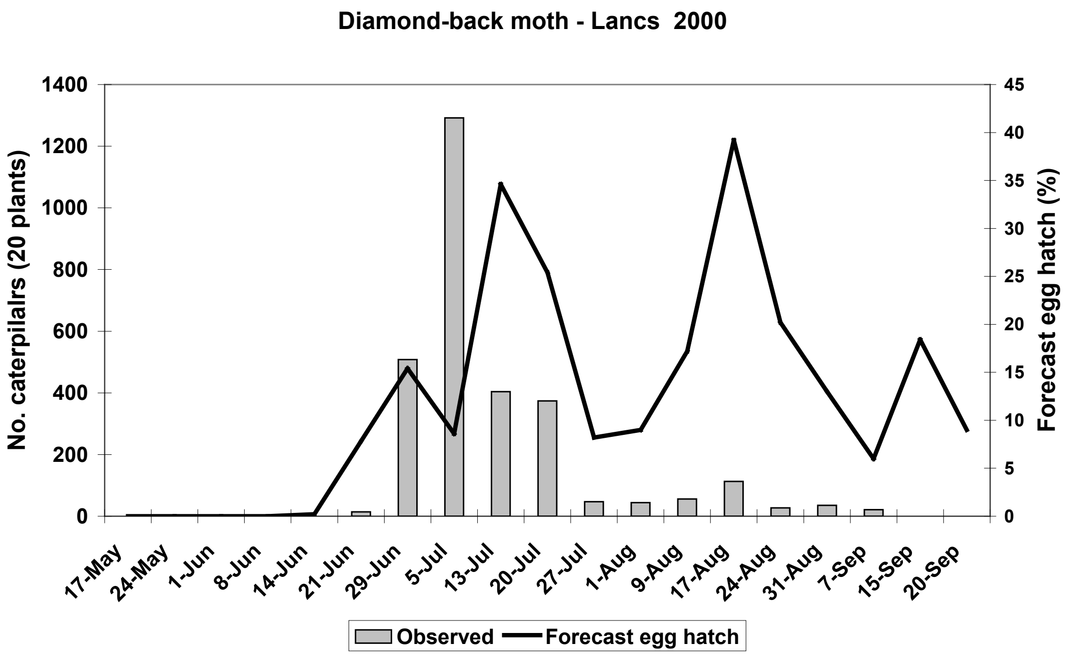
Appendix 11 Comparison of the numbers of diamond-back moth caterpillars found on untreated Brussels sprout plants with forecasts of egg hatch. The forecasts were generated using moth trap captures during the 'first' generation.





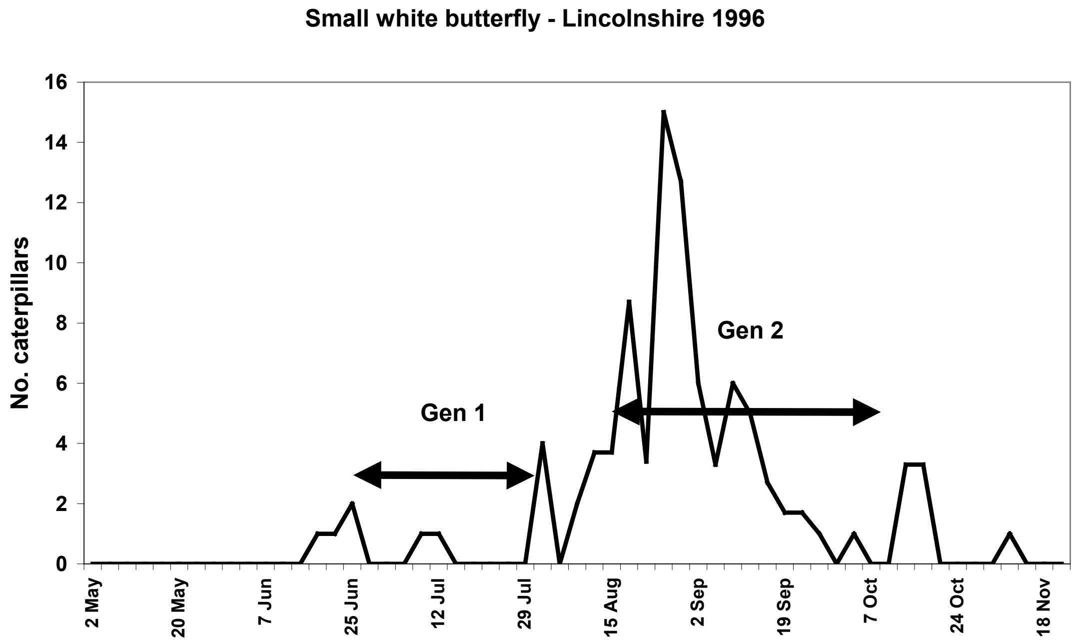
© 2001 Horticultural Development Council

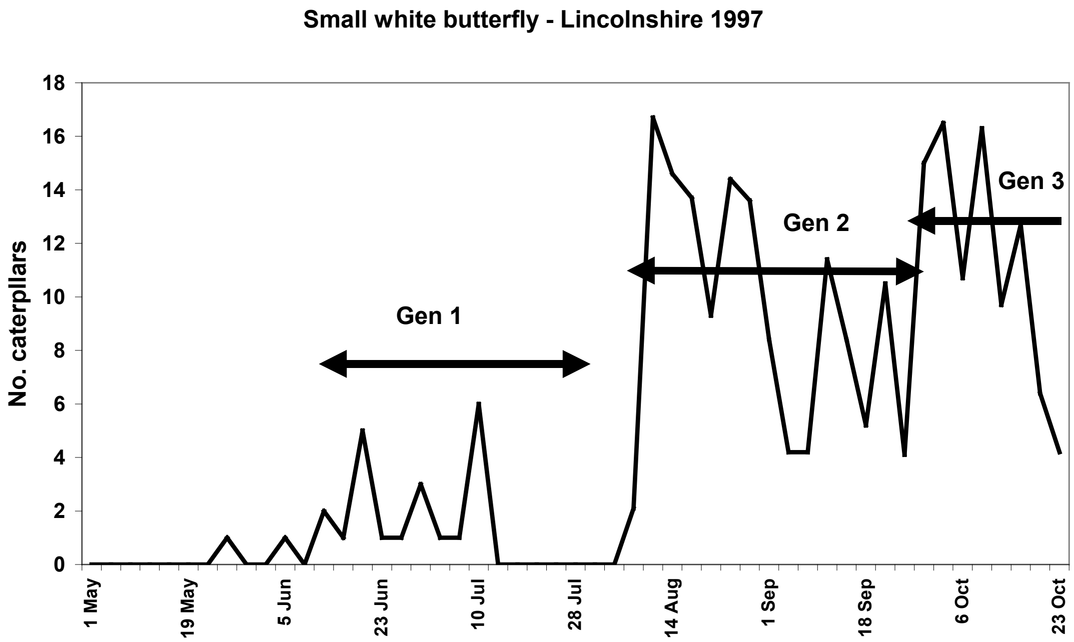
Appendix 11 Comparison of the numbers of diamond-back moth caterpillars found on untreated Brussels sprout plants with forecasts of egg hatch. The forecasts were generated using moth trap captures during the 'first' generation.



© 2001 Horticultural Development Council

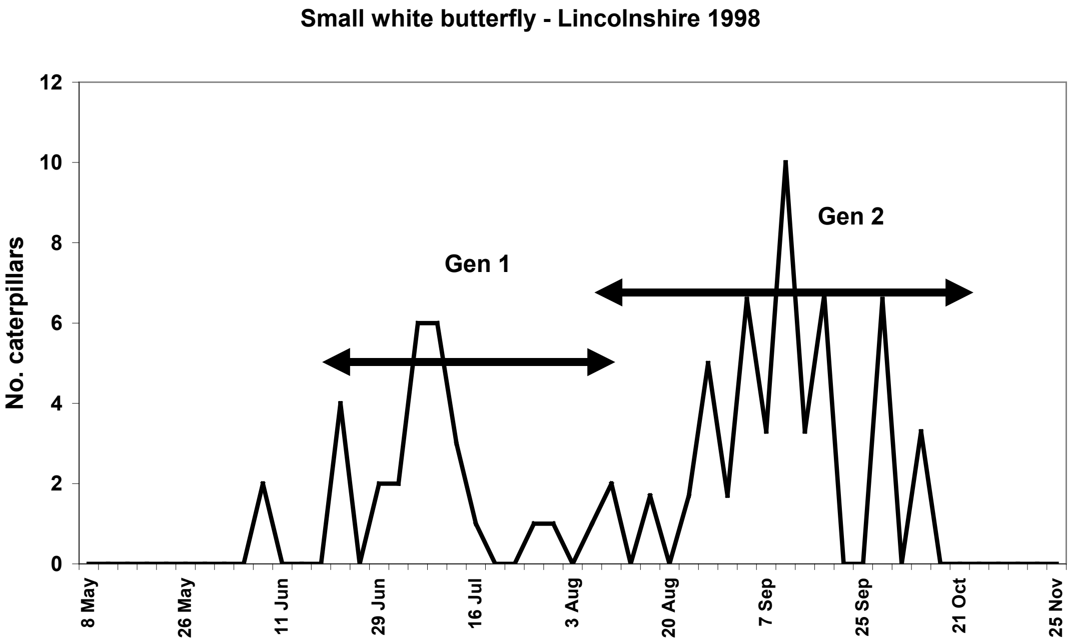
Appendix 12 Comparisons between observed and forecast small white butterfly activity. The horizontal lines with arrows indicate the periods when caterpillars would be expected from the forecast.

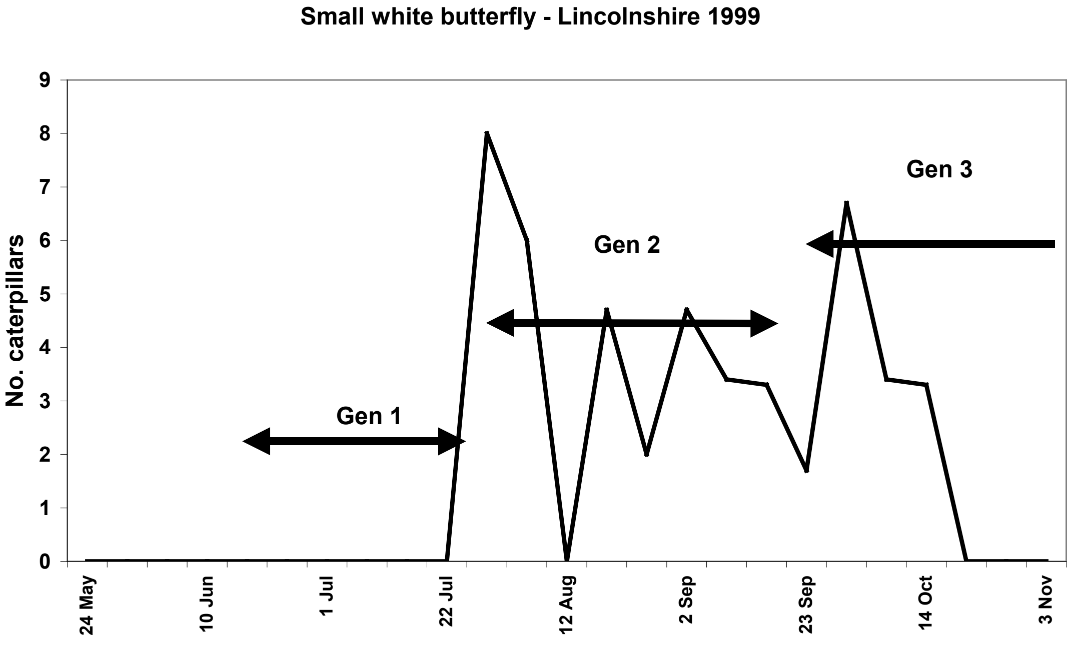




© 2001 Horticultural Development Council

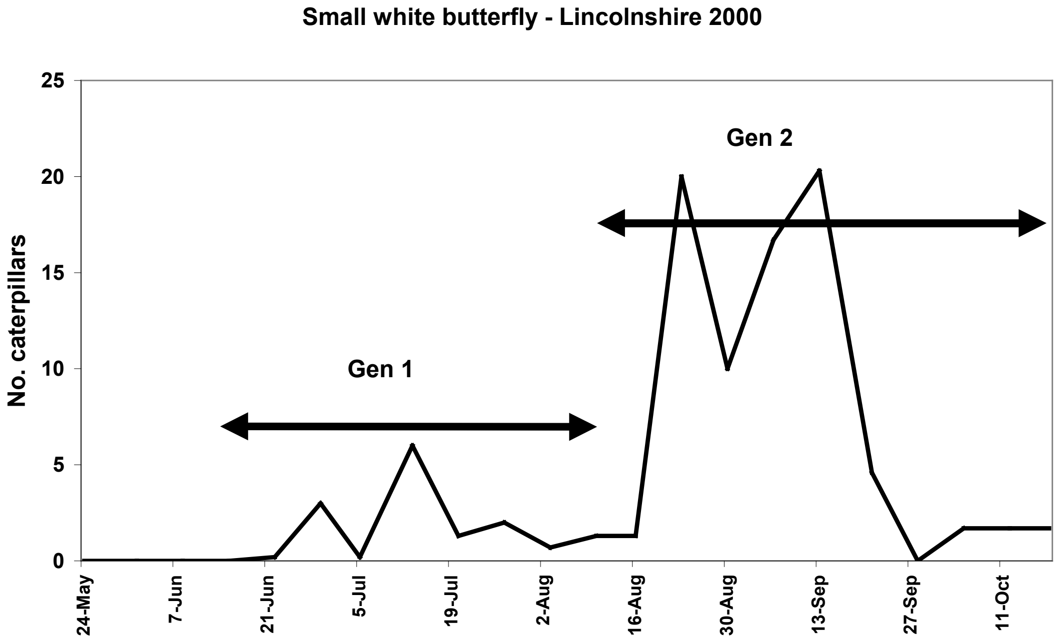
Appendix 12 Comparisons between observed and forecast small white butterfly activity. The horizontal lines with arrows indicate the periods when caterpillars would be expected from the forecast.





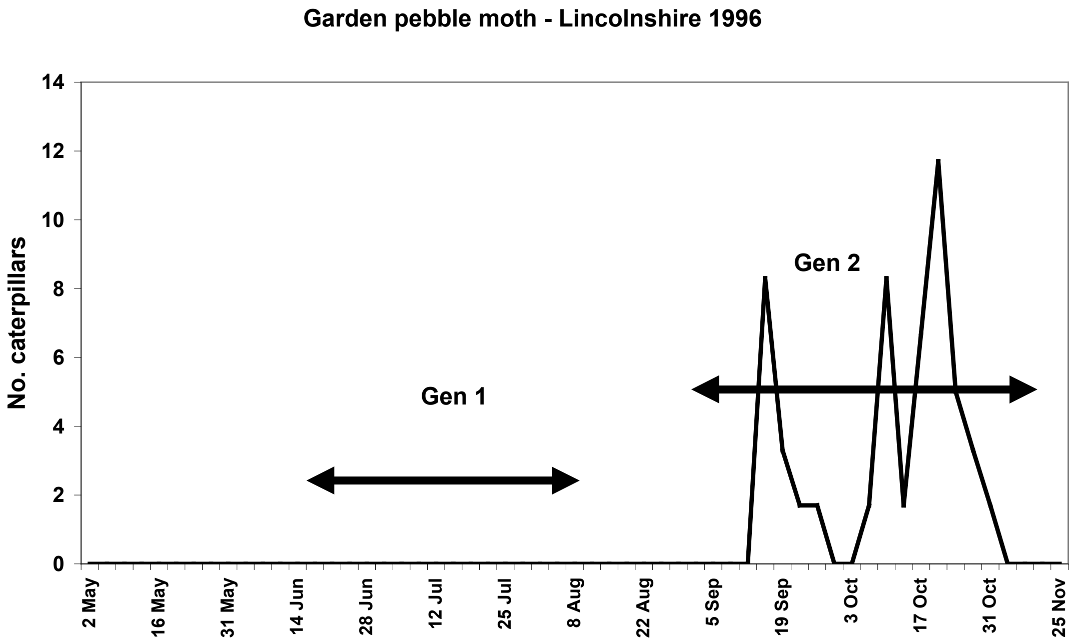
© 2001 Horticultural Development Council

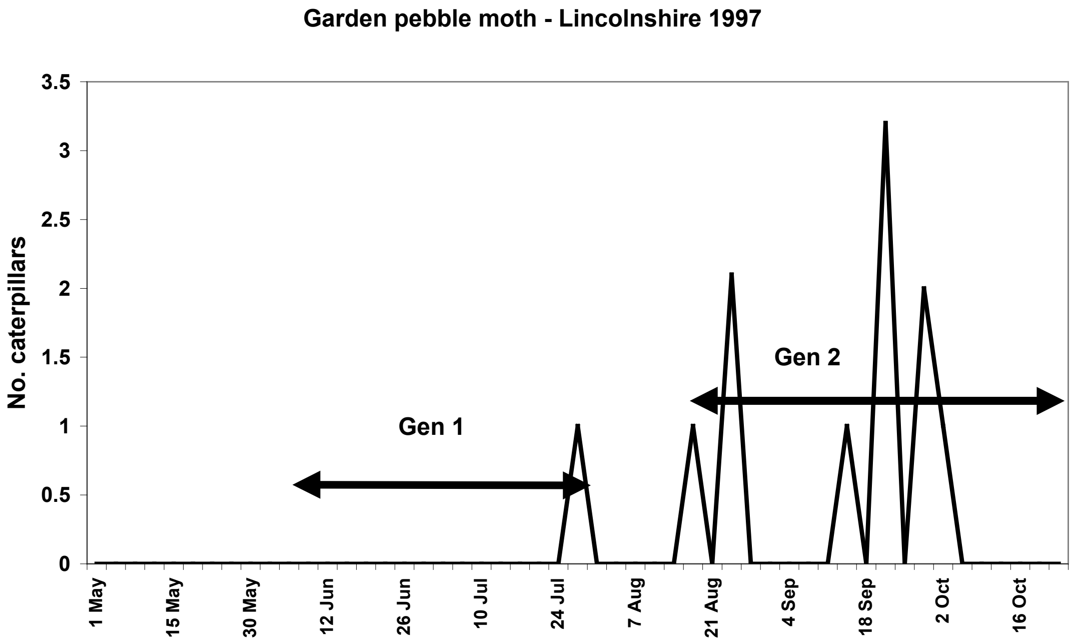
Appendix 12 Comparisons between observed and forecast small white butterfly activity. The horizontal lines with arrows indicate the periods when caterpillars would be expected from the forecast.



© 2001 Horticultural Development Council

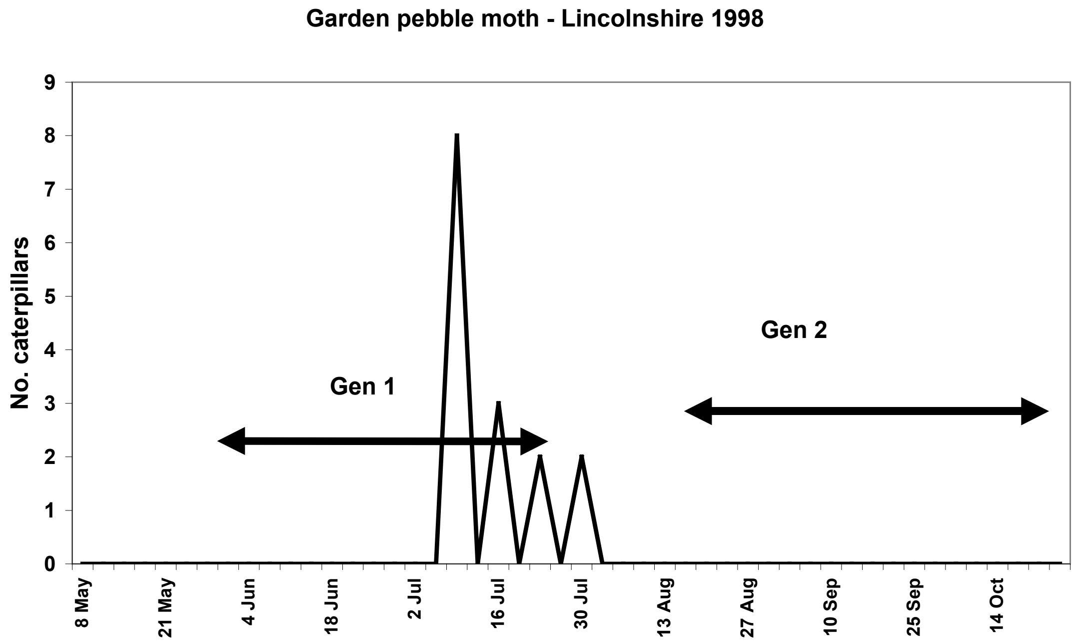
Appendix 13 Comparisons between observed and forecast garden pebble moth activity. The horizontal lines with arrows indicate the periods when caterpillars would be expected from the forecast.

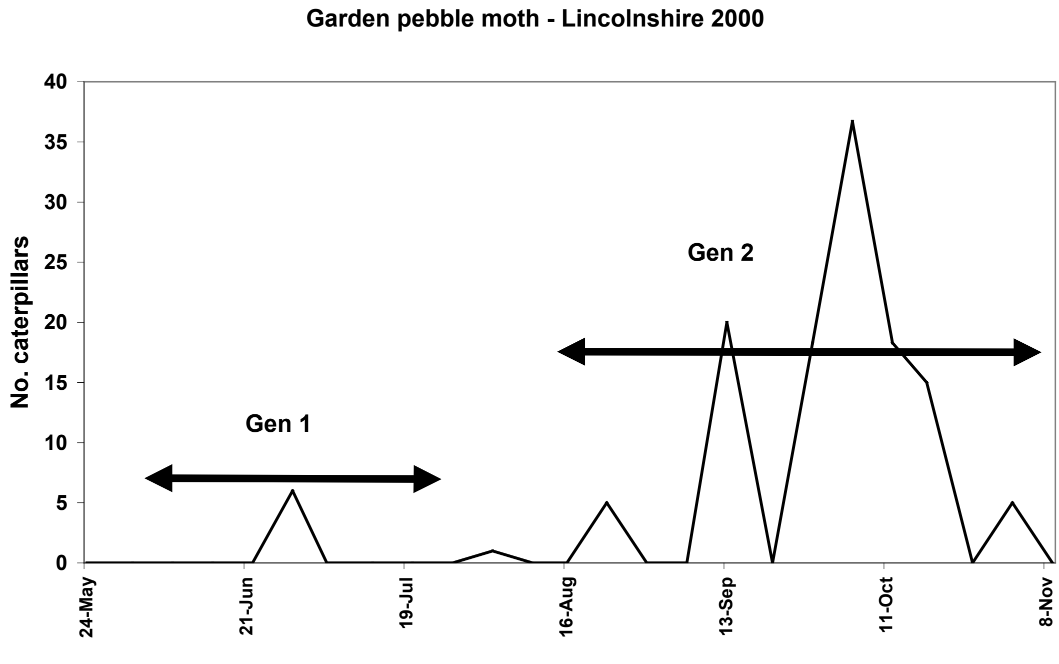




© 2001 Horticultural Development Council

Appendix 13 Comparisons between observed and forecast garden pebble moth activity. The horizontal lines with arrows indicate the periods when caterpillars would be expected from the forecast.





© 2001 Horticultural Development Council