Project title:	Improving codling moth spray timing
Project number:	TF 204
Project leader:	Professor Jerry Cross, East Malling Research
Report:	Final report 2015
Previous report:	Annual report 2013 Annual report 2014
Key staff:	Dr Michelle Fountain Adrian Harris
Location of project:	East Malling Research, New Road, East Malling, Kent, ME19 6BJ
Industry Representative:	Mark Holden, Adrian Scripps Ltd.
Date project commenced:	01 April 2012
Date project completed (or expected completion date):	31 March 2015

East Malling Research is an officially recognised efficacy testing station

DISCLAIMER

CONTENTS

GROWER SUMMARY

Headline

- Improved methods of timing sprays for codling moth have been developed.

Background and expected deliverables

Codling moth is the most important pest of apples in the UK and is also an important pest of pears. Control using traditional crop protection products is usually good, but populations are not being reduced to the low levels required to avoid use of sprays in subsequent years. UK growers generally rely on pheromone traps to decide if and when to spray for codling moth, but previous work in project TF189 suggested that they are of limited benefit and growers may not be making best use of their time and effort in using them. In the Netherlands, development and population simulations given by the RIMpro-Cydia model using data from local meteorological stations, has apparently provided growers with an accurate indication of the optimum time to apply sprays for control. The model, which is available to all growers, takes account of suitable conditions for egg laying (dusk temperatures >15 °C) as well as maturity and longevity of females, rather than activity of males as indicated by sex pheromone trap catches.

The purpose of this project was to assess three methods of deciding the best time to spray to control codling moth. These included the standard method of monitoring male moth flight using pheromone traps, use of the RIMpro-Cydia forecasting model in conjunction with pheromone trap records, and using the forecasting model in conjunction with an assessment of codling moth damage from the previous year. The work sought to develop improvements in control and/or savings in monitoring costs and management time.

Summary of the project and main conclusions

In 2014, the trial comparing the three methods was continued for a third year using the same plots in three commercial orchards in Kent. In the first year (2012), the sex pheromone trap threshold used was a count of ≥5 moths/trap/week in two weeks but not necessarily successive. In 2013 and 2014 this was amended to a single catch of ≥5 moths in June-July or ≥3 moths in August and September.

The RIMpro Cydia model parameters were also adjusted by the provider to give a greater proportion of the population entering a 2nd generation, which the model had failed to predict in 2013. Thus the insecticide timing methods were:

- Method 1: Standard method of monitoring male moth flight using pheromone traps and spraying after a threshold of ≥5 moths is exceeded in June-July or ≥3 moths is exceeded in August and September.

- Method 2: Use of the modified RIMpro-Cydia forecasting model in conjunction with pheromone trap records. Sprays only applied if both the model indicates egg laying risk and the pheromone trap threshold is exceeded.

- Method 3: Use of the modified RIMpro-Cydia forecasting model in conjunction with an assessment of codling moth damage the previous year to indicate general codling moth risk in the particular orchard.

The results of the project (set out in the Science Section of this report) led to the following overall conclusions:

1. The codling moth sex pheromone trap threshold should be lowered from ≥5 moths/trap/week in two weeks (not necessarily successive) to a single catch of ≥5 moths in June-July or ≥3 moths in August and September. There is little advantage of using Combo or Combo+AA (acetic acid) lures in orchards where mating disruption is not being used, as catches of females with these lures are too small and erratic. Further work is needed to validate these revised thresholds and investigate the use of alternative lures.

2. The RIMpro-Cydia model is a useful indicator of egg laying risk but the model needs calibrating. Use of an egg laying risk threshold of 100 in the RIMpro-Cydia model appears to overestimate egg laying risks and larval emergence which, if the model is used alone to time sprays, can result in much larger numbers of spray applications, many of which are probably unnecessary. It also appears to be difficult to set the parameters of the model to give reasonable predictions of the risks from 2nd generation egg-laying. Further, the sensitivity of the model and the proportion of the first generation that fed through from the 1st to the 2nd generation appeared to greatly increase when the model was converted to an online version for the 2014 season and

this needs to be corrected. These factors taken together indicate that although the model may give good predictions of relative risks, basic work is needed to calibrate it in terms of the scale of risks of egg laying and the proportion of the population producing a 2nd generation.

3. Use of the RIMpro-Cydia forecasting model in conjunction with pheromone trap records, only applying sprays if both the model indicates egg laying risks and the pheromone trap threshold exceeded (method 2) will help avoid unnecessary early sprays when males are flying but there is little or no risk of egg-laying.

4. The results from the project suggest that the interval between sprays for codling moth (expected cover period) should be reduced where significant (>1%) crop damage occurred the previous year or where trap catches are very high. An interval (cover period) of 2 weeks for Coragen, and 10 days for other products may be appropriate. The intervals should also be similarly reduced in periods of hot weather, when pesticide metabolism and breakdown, and fruit expansion are more rapid.

5. The importance of continuing to monitor and treat for codling moth in August and September is highlighted.

Financial benefits

Codling moth control programmes typically cost growers >£200/ha/season. Even a low level of fruit damage (0.3% fruits damaged) is likely to be economically unacceptable. Improving control and/or reducing insecticide use will be of financial benefit to growers.

Action points for growers

- Continue to use sex pheromone traps to monitor codling moth in orchards but use a lower threshold of a single catch of ≥5 moths in June-July or ≥3 moths in August and September.

- Where the RIMpro-Cydia forecasting model is used in conjunction with pheromone trap records, only apply sprays if both the model indicates egg laying risks and the pheromone trap threshold is exceeded, which will help to avoid unnecessary early sprays when males are flying but there is little or no risk of egg-laying.

- Reduce the interval between sprays for codling moth (expected cover period) where significant crop damage occurred the previous year (or trap catches are very high).

- Continuing to monitor for codling moth in August and September and treat when necessary.

SCIENCE SECTION

Summary

2014 (Year 3) season

In 2014, the trial comparing three methods of timing insecticide sprays for codling moth was continued for a third year using the same plots in three commercial orchards in Kent. The significant modification to the sex pheromone trap threshold (from ≥5 moths/trap/week in two weeks not necessarily successive in 2012 to a single catch of ≥5 moths in June-July or ≥3 moths in August and September in 2013 and 2014) was continued. The RIMpro Cydia model parameters were also adjusted by the provider to give a greater probability to second generation, which the model had failed to predict in 2013. The model was also converted to an online version. Thus the insecticide timing methods were:

- Method 1: Standard method of monitoring male moth flight using pheromone traps and spraying after a threshold of ≥5 moths is exceeded in June-July or ≥3 moths is exceeded in August and September;

- Method 2: Use of the modified RIMpro-Cydia forecasting model in conjunction with pheromone trap records. Sprays were only applied if both the model indicated egg laying risk and the pheromone trap threshold was exceeded;

- Method 3: Use of the modified RIMpro-Cydia forecasting model in conjunction with an assessment of codling moth damage the previous year to indicate general codling moth risk in the particular orchard.

In addition to sex pheromone and Combo traps (pear ester kairomone+sex pheromone) for codling moth, Combo traps containing an additional Acetic Acid (AA) lure (claimed to improve catches of females), were included for comparison.

The adjusted simpler sex pheromone trap thresholds (≥5 moths/trap/week in June-July, ≥3 moths/trap/week in August and September) performed satisfactorily in 2014. The ‘Trap’, ‘RIMpro’ and ‘RIMpro+trap’ treatments performed similarly in terms of control of codling moth and the resultant fruit damage. However, levels of damage (3.13-4.40% fruits) were too high and considerably above an economically acceptable level at one site, and marginally too high at the other sites, especially in the RIMpro+trap plots where there was1.48 and 0.96%

fruit damage at harvest. An economic damage threshold of 0.3% of fruits damage is appropriate bearing in mind the costs of treatment and the value of the fruit.

The results further suggest that the interval between sprays for codling moth (expected cover period) should be reduced where significant crop damage occurred the previous year or where trap catches are very high. The RIMpro model predicted significant fist generation egg laying risks almost continuously throughout June and July, resulting in a much greater number of insecticide applications at two sites, but there was no obvious benefit from these extra sprays in terms of improved control of codling moth. The model also predicted very high risks from second generation egg laying in September, though there was no indication that a second generation occurred, the reverse of the under prediction in 2013, this indicates that the model adjustment for the proportion of the population producing a second generation was too great.

The Combo traps caught >four times as many males as females, but in contrast to 2012 and 2013, generally in smaller numbers than the sex pheromone traps. Thus the sex pheromone trap lures are the most effective for monitoring males. Catches of females were low and erratic with both the Combo and the Combo+AA lures. Whilst Combo traps have a place for monitoring the success of sex pheromone mating disruption treatments, little real advantages over the sex pheromone traps were apparent for timing pesticide sprays. The main characteristic of the Combo+AA lure seems to be that fewer males are captured than when the Combo lure is used alone.

Overview of performance of the treatments in the three years of project

The Trap, RIMpro and RIMpro+trap spray timing methods resulted in grand averages of 1.8, 3.4 and 1.7 insecticide sprays, respectively. Thus the RIMpro treatment resulted in twice as many spay applications as the other two treatments, which performed similarly. Numbers of sprays roughly doubled with the Trap and RIMpro+trap methods in 2013 and 2014 due to the lowering of the pheromone trap threshold. Numbers of sprays for the RIMpro treatment roughly doubled in 2014 due to a combination of warmer weather and re-parameterisation of the RIMpro model. The Trap, RIMpro and RIMpro+trap spray timing methods resulted in grand averages of 3.2, 1.5 and 2.6% damage due to codling moth for the treatments respectively. The damage was consistently higher at one site.

Overall conclusions from the project

1. The codling moth sex pheromone trap threshold should be lowered from ≥5 moths/trap/week in two weeks (not necessarily successive) to a single catch of ≥5 moths in June-July or ≥3 moths in August and September. There is little advantage of using Combo or Combo+AA (acetic acid) lures in orchards where mating disruption is not being used as catches of females with these lures are too low and erratic. Further work is needed to validate these revised thresholds and investigate the use of alternative lures.

2. The RIMpro-Cydia model is a useful indicator of egg laying risk but the model needs calibrating. Use of an egg laying risk threshold of 100 in the RIMpro-Cydia model appears to overestimate egg laying risks and larval emergence which, if the model is used alone to time sprays, can result in much higher numbers of spray applications, many of which are probably unnecessary. It also appears to be difficult to set the parameters of the model to give reasonable predictions of the risks from second generation egg-laying. Further, the sensitivity of the model and the proportion of the first generation that fed through from the first to the second generation appeared to greatly increase when the model was converted to an online version for the 2014 season and this needs to be corrected. These factors taken together indicate that although the model may give good predictions of relative risks, basic work is needed to calibrate it in terms of the scale of risks of egg laying and the proportion of the population producing a second generation.

3. Use of the RIMpro-Cydia forecasting model in conjunction with pheromone trap records, only applying sprays if both the model indicates egg laying risks and the pheromone trap threshold exceeded (Method 2) will help avoid unnecessary early sprays when males are flying but there is little or no risk of egg-laying.

4. The results from the project suggest that the interval between sprays for codling moth (expected cover period) should be reduced where significant (>>1%) crop damage occurred the previous year or where trap catches are very high. An interval (cover period) of two weeks for Coragen, and 10 days for other products may be appropriate. The intervals should also be similarly reduced in periods of hot weather, when pesticide metabolism and breakdown, and fruit expansion are more rapid.

5. The importance of continuing to monitor and treat for codling moth in August and September is highlighted.

Introduction

Codling moth is the most important pest of apples and also an important pest of pears in the UK. Most insecticide sprays on apple are used against it. Codling moth control programmes typically cost growers >£200/ha/season. Control is usually good, but populations are not being reduced to such low levels that spraying is reduced in subsequent years: growers are on an insecticide treadmill. UK growers generally rely on pheromone traps to decide if and when to spray for codling moth but previous work in project TF189 suggested that they are of limited benefit and growers may not be making best use of their time and effort in using them. Experience in the Netherlands indicates that control of codling moth which is as good or better can be obtained using development and population simulations provided by the RIMpro-Cydia model using data from local met stations. The model, which is available to all growers, takes into account when conditions suitable for egg laying occur (dusk temperatures >15 °C) as well as maturity and longevity of females rather than activity of males as indicated by sex pheromone trap catches. This work will determine which of the three alternative decision-making methods would best lead to improvements in control and/or savings in monitoring costs and management time.

Objectives

The general aim of this project was to determine better practical methods for timing sprays of insecticides for control of codling moth on apple and pear in the UK, so reducing overwintering populations and achieving better long term control. The specific objective was to determine which of the following methods is best for timing insecticide sprays to get the most cost effective control of codling moth, including in the long term:

- Method 1 ‘Trap’: Standard method of monitoring male moth flight using pheromone traps and spraying after a threshold of ≥5 moths is exceeded in June-July or ≥3 moths is exceeded in August and September;

- Method 2 ‘RIMpro+trap’: Use of the RIMpro-Cydia forecasting model in conjunction with pheromone trap records. Sprays only applied if both the model indicates an egg laying risk and the pheromone trap threshold is exceeded;

- Method 3 ‘RIMpro’: Use of the RIMpro-Cydia forecasting model in conjunction with an assessment of codling moth damage the previous year to indicate general codling moth risk in the particular orchard.

Outline of work

Three large dessert apple orchards on different farms in southern England were each divided into three plots, each plot receiving sprays for codling moth using one of the three different timing methods for three successive years (2012-2014).

The same insecticides were used (Coragen (chlorantraniliprole), Steward (indoxacarb) and chlorpyrifos) as in 2013 but it was anticipated that the different methods of spray timing would result in different timings and numbers of sprays being applied. The orchards chosen had a history of significant codling moth pheromone catches and each had a local, high quality, calibrated weather station nearby. Adult codling moth populations in each plot were monitored with a sex pheromone and a pear ester kairomone + sex pheromone Combo trap, with an additional Triple trap (Combo+Acetic Acid) in 2014. Larval attack to fruits was assessed in July (first generation) and at harvest. Each year the forecasts generated, and the comparative success of the different methods, were judged in terms of the standard of control achieved, the numbers of larvae overwintering and the numbers and costs of insecticides used.

Materials and methods

Sites

Site 1 (Advisor Paul Bennett, Agrovista): In 'Mealy Meads' Bramley orchard at Amsbury Farm, East Street, Hunton, ME15 0Q, by kind agreement of Clive Baxter (owner) and with help of farm manager Alan Burbridge and spray operator David Gosling (spraying) (Table 1, Figure 1).

Site 2 (Advisor Paul Bennett, Agrovista): In 'Old Orchard' Jonagold at West Pikefish Farm, Laddingford, Maidstone, Kent, ME18 6BH, by kind agreement of James Smith (owner) (Table 1, Figure 1).

Site 3 (Advisor Tim Biddlecombe, FAST): In 'Deerson' Kanzi orchard at Adrian Scripps Ltd, Wenderton Farm, Wenderton Lane, Wingham, Canterbury, Kent, CT3 1EL, by kind agreement of manager Mark Holden and local farm manager Russell Graydon (Table 1, Figure 1).

Table 1. Details of the orchards where the trials are located

Site 1. Amsbury Farm	
National grid reference	TQ 738 500
Orchard name	Mealy Meads
Variety	Bramley
Rootstock	MM106
Planting date	>25 years ago
Area	1.0 ha
System	Single row
Row spacing	18' (= 5.5 m)
Tree spacing in row	9' (= 2.75 m)
Tree density	661 trees/ha
Tree row height	4
CAF factor at full leaf	1
Site 2. West Pikefish Farm	
National grid reference	TQ 695 475
Orchard names	Old Orchard
Variety	Jonagold
Rootstock	M9
Planting date	Winter 2008/09
Area	2.65 ha
System	Single row
Row spacing	4 m
Tree spacing in row	1 m
Tree density	2500 trees/ha
Tree row height	
CAF factor at full leaf	
Site 3. Wenderton Farm	
National grid reference	TR 243 595
Orchard name	Deerson
Variety	Kanzi
Rootstock	M9
Planting date	Spring 2004
Area	13 ha
System	Single row
Row spacing	3.75 m
Tree spacing in row	1.25 m
Tree density	2133 trees/ha
Tree row height	2.5 m
CAF factor at full leaf	1.0

Site 1. Amsbury Farm
MM106 Bramley >25 yr old
1 ha; 666 trees/ha

Site 2. W. Pikefish Farm
M9 Jonagold 3 yr old
2.7 ha; 2500 trees/ha

Site 3. Wenderton Farm
M9 Kanzi 8 yr old
7 ha; 2500 trees/ha

Figure 1. Typical apple trees in the three orchards at the three sites

Treatments

In collaboration with the host grower, each plot received sprays for codling moth using one of three different scheduling/timing methods (Table 2). 2013 was the second year of the experiment, which will continue for one further year (2014). In 2013, based on the findings of the work in 2012, the threshold for spraying for codling moth was lowered from a catch of ≥5 moths in two weeks, not necessarily successive, to a single catch of ≥5 moths in June-July or a single catch of ≥3 moths per trap in August and September. Insecticides, their preferred order of use and recommended rates are given in Table 3.

Table 2. Treatments

Trt No.	Colour code and name	Method of timing sprays for codling moth
1	Green (G) Trap	Standard method of monitoring male moth flight using delta pheromone traps with sticky inserts and spraying after a threshold of ≥5 moths is exceeded in June-July or ≥3 moths is exceeded in August and September
2	Red (R) RIMpro+trap	Use of the RIMpro-Cydia forecasting model in conjunction with pheromone trap records. Sprays only applied if both model indicates egg laying risk and pheromone trap threshold exceeded
3	Blue (B) RIMpro	Use of the RIMpro-Cydia forecasting model in conjunction with an assessment of codling moth damage the previous year to indicate general codling moth risk in the particular orchard

Table 3. Insecticides to be used for codling moth

Product	Rate (/ha)	Max no. sprays/ season	Harvest interval (days)	Spray volume (l/ha)		
				Site 1	Site 2	Site 3
Coragen (chlorantraniliprole)	175 ml	2	14	500	200	250
Steward, Explicit (indoxacarb)	250 g‡	3	7	500	200	250
Chlorpyrifos 480 g/l	2.0 l	3*	14	500	200	250

‡For 3.75 m tall trees. Reduce dose according to height, but not below 170 g/ha
*Post blossom at this rate

Experimental design and statistical analyses

Each orchard was divided into three large (approximately equal sized) plots. The allocation of plots to treatments is given in Table 4. Diagrams of the layouts of the trials are given in Figures 2-4 for the three sites, respectively.

Table 4. Allocation of treatments to plots

Site 1 (Amsbury) (Figure 2)			Site 2 (West Pikefish) (Figure 3)			Site 3 (Wenderton) (Figure 4)		
Plot no.	Treatment method		Plot no.	Treatment method		Plot no.	Treatment method	
	Col.	Method		Col.	Method		Col.	Method
101	G	Trap	201	B	RIMpro	301	R	RIMpro+trap
102	R	RIMpro+trap	202	G	Trap	302	B	RIMpro
103	B	RIMpro	203	R	RIMpro+trap	303	G	Trap

Figure 2. Plots and traps in Mealy Meads orchard at Amsbury Farm

Figure 3. Plots and traps in young Jonagold orchard at West Pikefish Farm

Figure 4. Plots and traps in Deerson orchard at Wenderton Farm

Treatment application

Sprays were applied by the host grower using the growers' normal spray application equipment and spray volume.

Meteorological records

The three farms each have a good quality, calibrated met station. Each year in late winter/early spring, the calibration of the local met station used for obtaining met data for the model are checked.

Assessments

A sex pheromone trap for codling moth, summer fruit tortrix moth and fruit tree tortrix moth and a codling moth Combo trap and Combo trap with additional acetic acid lure was deployed in the centre of each plot and monitored weekly throughout the season with assistance from the host grower. For locations of the traps see Figures 2-4 for the three sites.

Larval attack to fruits was assessed in each plot in July (first generation) and at harvest on samples of at least 1000 fruits per plot. A fixed number of trees were assessed at each farm, depending on fruit load and tree size. The assessments included fruit on the tree and dropped/fallen fruits.

Each year, the forecasts generated and the comparative success of the different methods were judged in terms of the standard of control achieved, the numbers of larvae overwintering and the numbers and costs of insecticides used.

Results and discussion

Codling moth

Trap treatment

Amsbury Farm:

Codling moth trap catches (Figure 5) exceeded the threshold of five moths per trap per week on 22 May, 12, 19, 26 June and 3, 10, 17, 24, 31 July with a particularly high catch (36) on 10 July (Table 5). Trap catches were at or below the late season threshold of two per trap throughout August and early September (records were terminated on 11 September). Four alternating sprays of Coragen and Steward were applied on 31 May, 19 June, 10 and 25 July, respectively. A low level of damage (0.66%) was present in late July/early August but 3.42% of fruit were found to be damaged by codling moth at harvest. Note that the last spray of Steward on 25 July scarcely covered the above threshold catch (of seven) on 31 July. This may be the reason for the unacceptably high (3.42%) level of damage at harvest.

West Pikefish Farm:

Codling moth sex pheromone trap catches (Figure 5) of 9 on 20 May and 36 on 17 June triggered sprays of Coragen and Steward on 5 and 26 June, respectively (Table 5). Trap catches were at or below the late season threshold of three per trap throughout August and September. A low level of damage (0.53%) was present in late July/early August and 0.66% of fruit were found to be damaged by codling moth at harvest (Table 6). Applying sprays according to trap catches using the new threshold (single catches of five per trap per week May-July, two per trap per week August-September) gave a fully satisfactory result as very good control was achieved with a minimal number of insecticide applications.

Wenderton Farm:

Codling moth sex pheromone trap catches (Figure 5) of 20 then seven on 9 and 16 June, respectively, triggered a spray of Coragen on 18 June. Trap catches did not exceed threshold for the rest of the season. A low level (0.76%) of damage was present in late July/early August and only 0.29% of fruit were found to be damaged by codling moth at harvest. Applying sprays according to trap catches using the new threshold (single catches of five per trap per week May-July, three per trap per week August-September) gave a fully satisfactory result as very good control was achieved with just one insecticide application.

RIMpro treatment

Amsbury Farm:

RIMpro–Cydia model predictions using data from the met station at Westerhill Farm, nearby, showed high levels of egg laying well above 100 on the risk scale on 1,2,6-29 June, 2-6,10,13,14 July and 3-15 August (Figure 8, Table 5). Larval hatch was predicted to occur more or less continuously between 13 June and early August (Figure 8). Four alternating sprays of Coragen and Steward were applied on 10 and 25 Jun, 16 Jul and 15 Aug. A very low level of damage (0.35%) was present in late July/early August but 3.13% of fruit were found to be damaged by codling moth at harvest. This poor control despite four sprays might be due to gaps in the programme or because the fruit was harvested slightly later than anticipated, in mid-September rather than end of August.

West Pikefish Farm:

RIMpro–Cydia model predictions using data from the farm met station showed high levels of egg laying well above 100 on the risk scale on 1,2,6-29 June, 2-6,10,13-14,16 July, 3-28 August (Figure 8, Table 5). Larval hatch was predicted to occur more or less continuously between mid-June and early August (Figure 7). A programme of five sprays of insecticides (Coragen, Explicit, Coragen, Explicit, Steward) was applied on 16 June, 3 and 16 July, 13 and 28 August (Table 5). A low level of damage (0.37%) was present in late July/early August and 0.81% of fruit were found to be damaged by codling moth at harvest. Control was satisfactory but not substantively better than the Trap or the RIMpro+trap plots where only two sprays were applied.

Wenderton Farm:

RIMpro–Cydia model predictions using data from the farm met station showed significant levels of egg laying at and often significantly above 100 on the risk scale on 6-17,19,21-25,27,29 June,1-5,7-10,12-19 July, 7-25, 27-30 August (Table 5, Figure 7). Five insecticide sprays (Coragen, Steward, Coragen, Explicit, Steward) were applied on 18 Jun, 4 and 21 July and15 and 30 August, respectively (Table 5). A low level of fruit damage (0.4%) was present in late July/early August and 0.4% of fruit were found to be damaged by codling moth at harvest. Control at West Pikefish Farm was satisfactory but not substantively better than the Trap or the RIMpro+trap plots where only one spray was applied.

RIMpro+trap treatment

Amsbury Farm:

The risk from both trap and RIMpro predictions led to three sprays (Steward, Coragen, Steward) being applied on 19 June and 10 and 25 July (Table 5). A very low level of damage (0.34%) was present in late July/early August but 4.4% of fruit were found to be damaged by codling moth at harvest (Table 6).

West Pikefish Farm:

The risk from both trap and RIMpro predictions led to sprays of Coragen and Steward on 16 June and 28 August. A low level of damage (0.32%) was present in late July/early August and 1.48% of fruit were found to be damaged by codling moth at harvest.

Wenderton Farm:

The risk from both trap and RIMPro predictions led to a spray of Coragen on 18 June. A low level of damage (0.41%) was present in late July/early August and only 0.96% of fruit were found to be damaged by codling moth at harvest (Table 6).

Tortrix moths

Sex pheromone trap catches of fruit tree tortrix moths were greatest at Wenderton Farm, where they exceeded the threshold of 30 moths per trap in all plots in early to mid-June. There was a lull in flight activity in late June with a slight resurgence in July. There were slight signs of a partial second peak in August in the Trap plot (Figure 9). Catches at Amsbury Farm and Pikefish Farm were lower but the threshold of 30 moths per tap per week was exceeded or nearly so in all plots on these two farms in June except the RIMpro+trap plot at Amsbury Farm. Catches of summer fruit tortrix moth were very low in all plots at all sites (Figure 10). Damage to fruits due to tortrix moth larvae was negligible (Table 7).

Comparative performance of lures

The sex pheromone traps caught the greatest numbers of males (grand total 381), 1.7 times as many as the Combo traps (230) and 3.2 times as many as the Combo+AA traps (120) (Table 8). The Combo and Combo+AA baited traps caught similar numbers of females (grand totals 49 and 46, respectively) (Table 8). However, the numbers of females caught with both the Combo and Combo+AA traps were still small (seasons total averaging five per trap) and erratic. For the Combo traps, the greatest numbers of females were caught at Amsbury Farm, where crop damage was greatest, but a clear relationship between female catches and damage was not apparent, which is not surprising as the amount of damage would have been greatly affected by the insecticide sprays applied. There was no obvious relationship between the numbers of females caught in the Combo only traps and the Combo+AA traps.

In summary, the Combo traps caught >4 times as many males as females, but in contrast to 2012 and 2013, generally in smaller numbers than the sex pheromone traps. Thus the sex pheromone traps lures were the most effective for monitoring males. Catches of females were small and erratic with both the Combo and the Combo+AA lures. Whilst Combo traps have a place for monitoring the success of sex pheromone mating disruption treatments, no real advantages over the sex pheromone traps were apparent for timing pesticide sprays. The main characteristic of the additional AA lure seems to be that fewer males are captured than when the Combo lure is used alone.

Table 5. Dates of application of insecticide sprays according to treatment

Site	Trap Product	Appli-cation date	Trap thresholds trigger		RIMpro Product	Appli-cation date	RIMpro egg risk dates	RIMpro+trap Product	Appli-cation date
Amsbury	Coragen	31 May	12	22 May	Coragen	10 Jun	1,2,6,7,8,9,10 Jun	Steward	19 Jun
	Steward	19 Jun	5,6	12,19 Jun	Steward	25 Jun	11-25 Jun	Coragen	10 Jul
	Coragen	10 Jul	11,9,36	26 Jun, 3,10 Jul	Coragen	16 Jul	26-29 Jun, 2-6,10,13,14 Jul	Steward	25 Jul
	Steward	25 Jul	20,7	17,24 Jul	Steward	15-Aug	3-15 Aug		
Pikefish	Coragen	5 Jun	9	20 May	Coragen	16 Jun	1,2,6-16 Jun	Coragen	16 Jun
	Steward	26 Jun	36	17 Jun	Explicit	3 Jul	17-29 Jun, 2-3 Jul	Steward	28 Aug
					Coragen	16 Jul	4-6,10,13-14,16 Jul		
					Explicit	13 Aug	3-13 Aug		
					Steward	28 Aug	14-28 Aug		
Wenderton	Coragen	18 Jun	20,7	9,16 Jun	Coragen	18 Jun	6-17 Jun	Coragen	18 Jun
					Steward	4 Jul	19,21-25,27,29 Jun,1-4 Jul		
					Coragen	21 Jul	5,7-10,12-19 Jul		
					Explicit	15 Aug	7-15 Aug		
					Steward	30 Aug	16-25,27-30 Aug		

Table 6. Total number and percentage fruits damaged by codling moth

	Trap		RIMpro		RIMpro + trap	
	no:/ha	**%**	**no:/ha**	**%**	**no:/ha**	**%**
			First gen on tree and dropped July/August			
Amsbury	1719	0.66	1058	0.35	1058	0.34
Pikefish	2000	0.53	1250	0.37	1375	0.32
Wenderton	2133	0.76	1067	0.40	1067	0.41
			At harvest picked and dropped September/October			
Amsbury	5141	3.42	2791	3.13	4921	4.40
Pikefish	325	0.66	200	0.44	650	1.48
Wenderton	104	0.29	104	0.40	296	0.96

Table 7. Number and percentage fruits damaged by tortrix moth at harvest in September-October. Note virtually no damage was recoded at the July/August assessment

	Trap		RIMpro		RIMpro + trap	
	no:/ha	**%**	**no:/ha**	**%**	**no:/ha**	**%**
Amsbury	661	0.44	73	0.08	367	0.33
Pikefish	25	0.05	0	0	75	0.17
Wenderton	148.	0.42	30	0.11	119	0.38

Table 8. Total catches of codling moth adults in traps with the different lures from week 24-38

Site	Treatment	Lure				
		Combo		**AA**		**Phero**
		Males	**Females**	**Males**	**Females**	**Males**
Amsbury	Trap	49	9	6	3	102
	RIMpro+trap	32	7	3	1	81
	RIMpro	47	8	4	3	22
Pikefish	Trap	10	8	8	5	57
	RIMpro+trap	10	6	10	7	23
	RIMpro	7	5	10	13	18
Wenderton	Trap	33	0	33	0	34
	RIMpro+trap	23	5	25	12	18
	RIMpro	19	1	21	2	26
Grand total		230	49	120	46	381

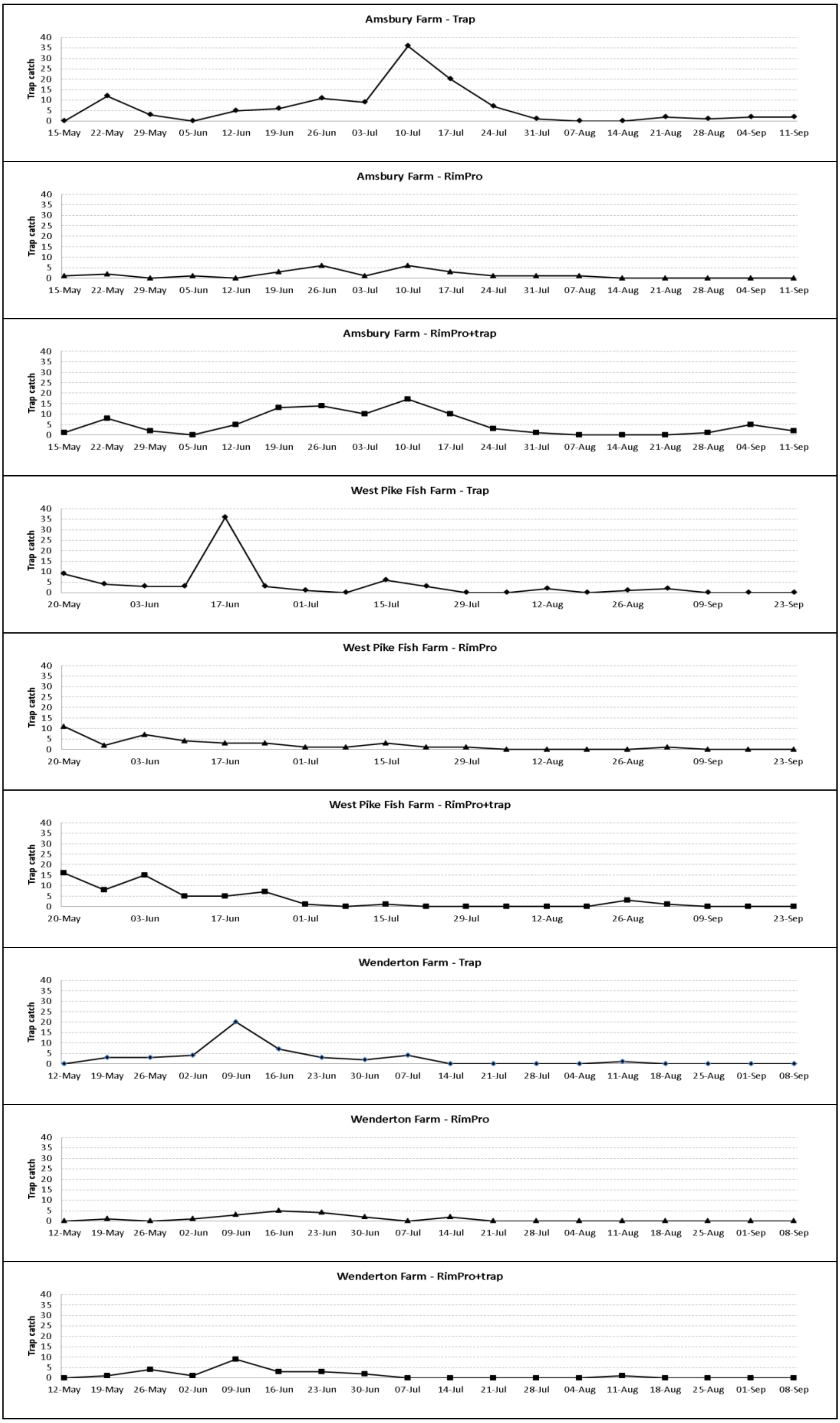

Figure 5. Codling moth sex pheromone trap catches

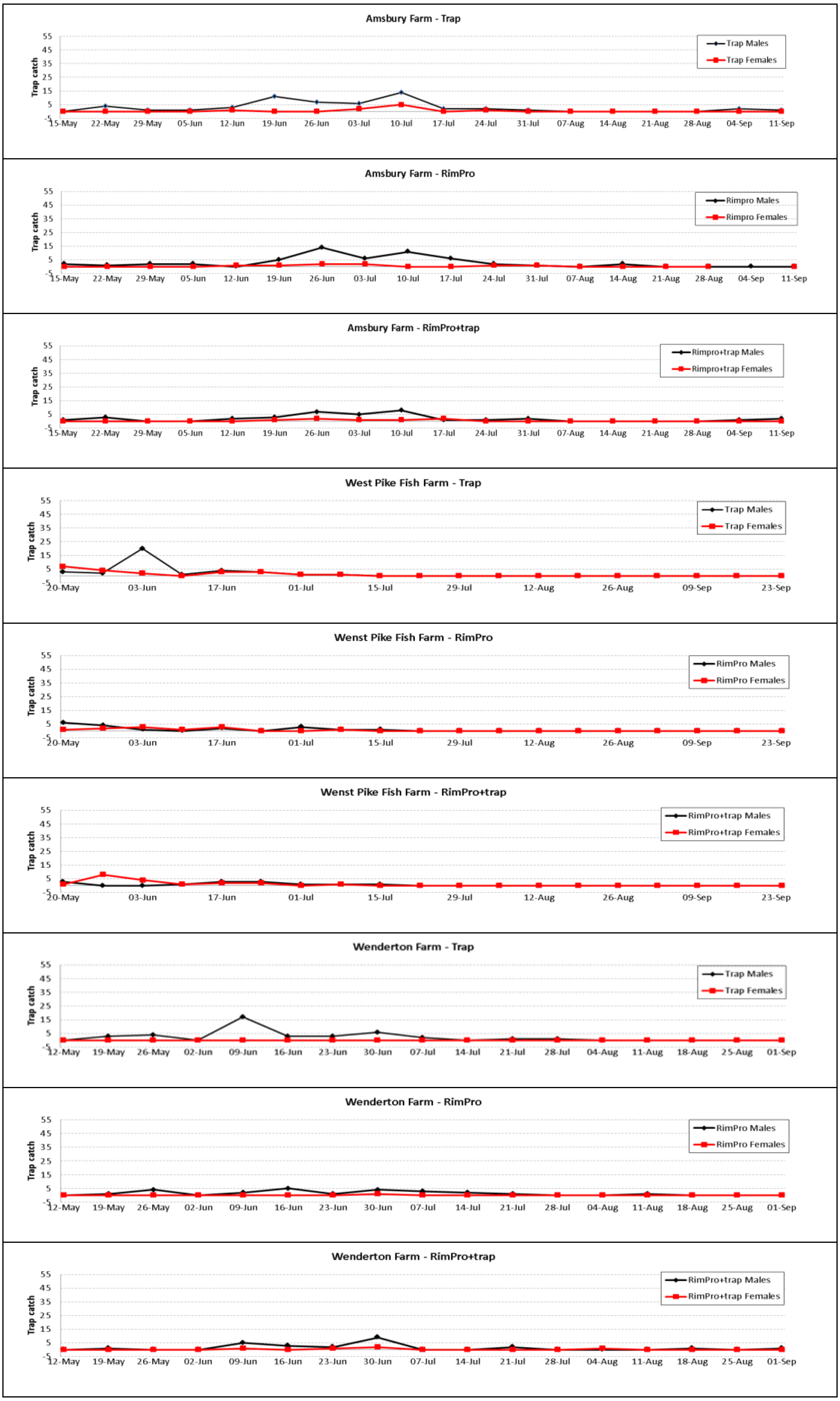

Figure 6. Codling moth Combo trap catches

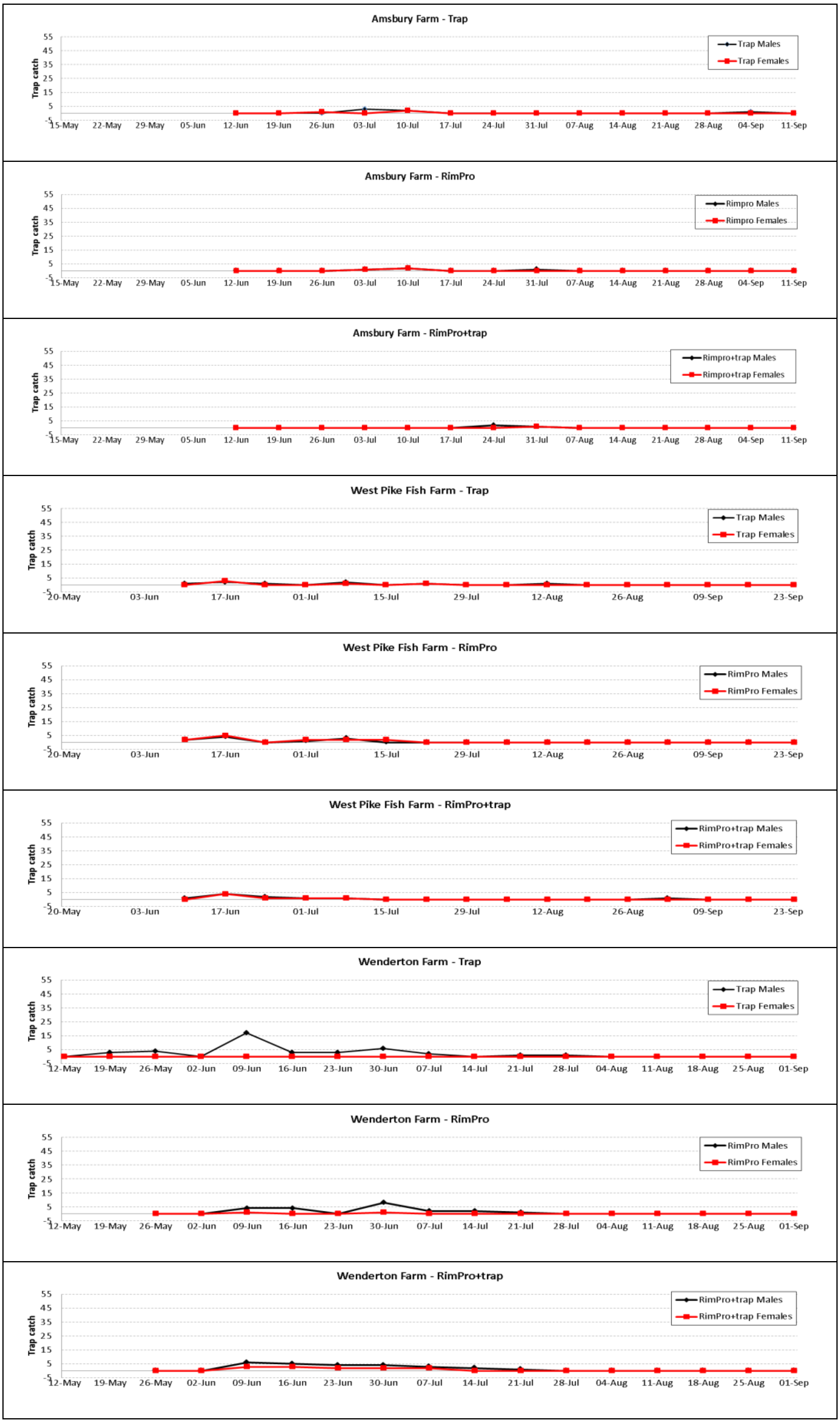

Figure 7. Codling moth AA trap catches

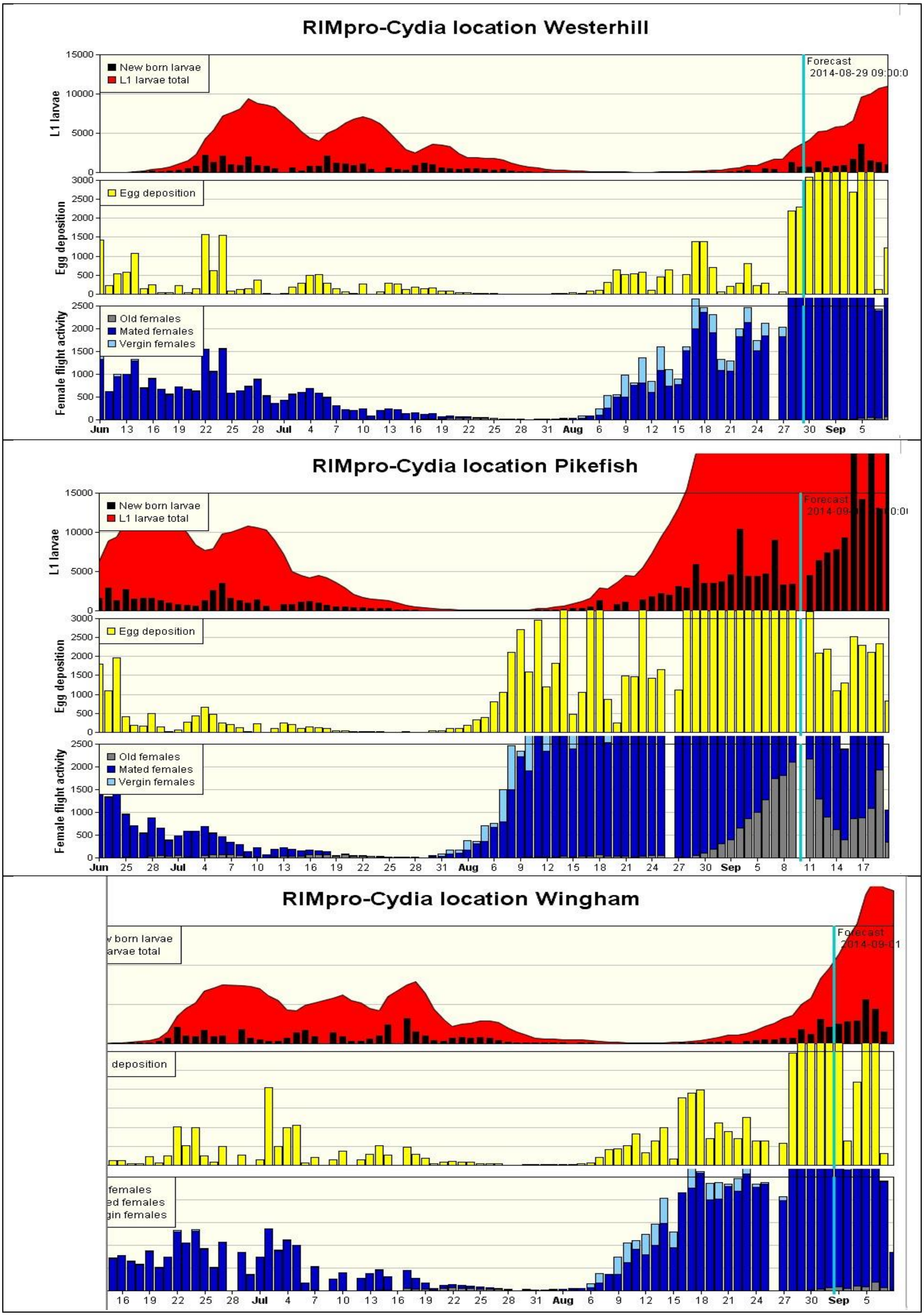

Figure 8. RIMpro-Cydia model predictions for the three sites in 2014

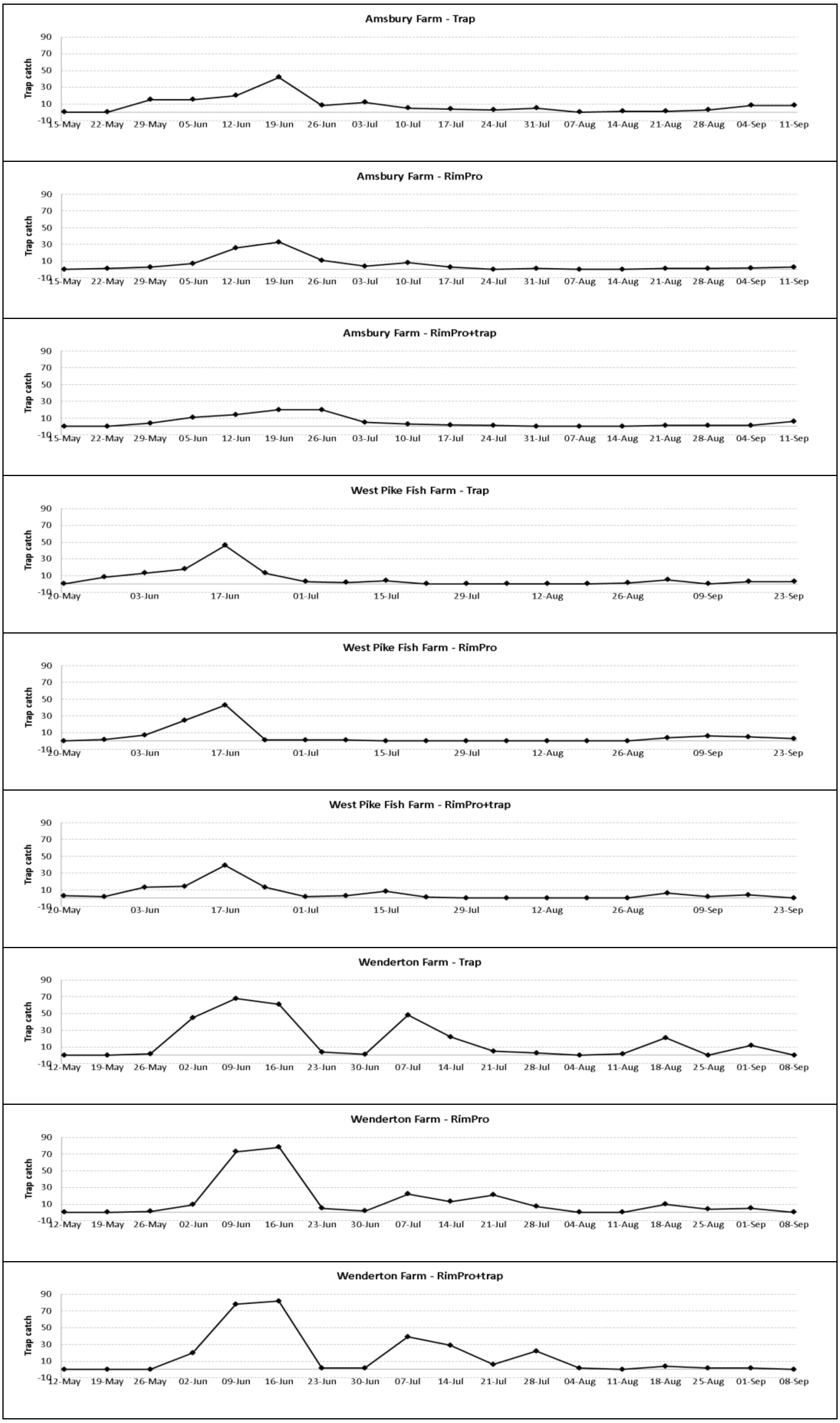

Figure 9. Fruit tree tortrix moth sex pheromone trap catches

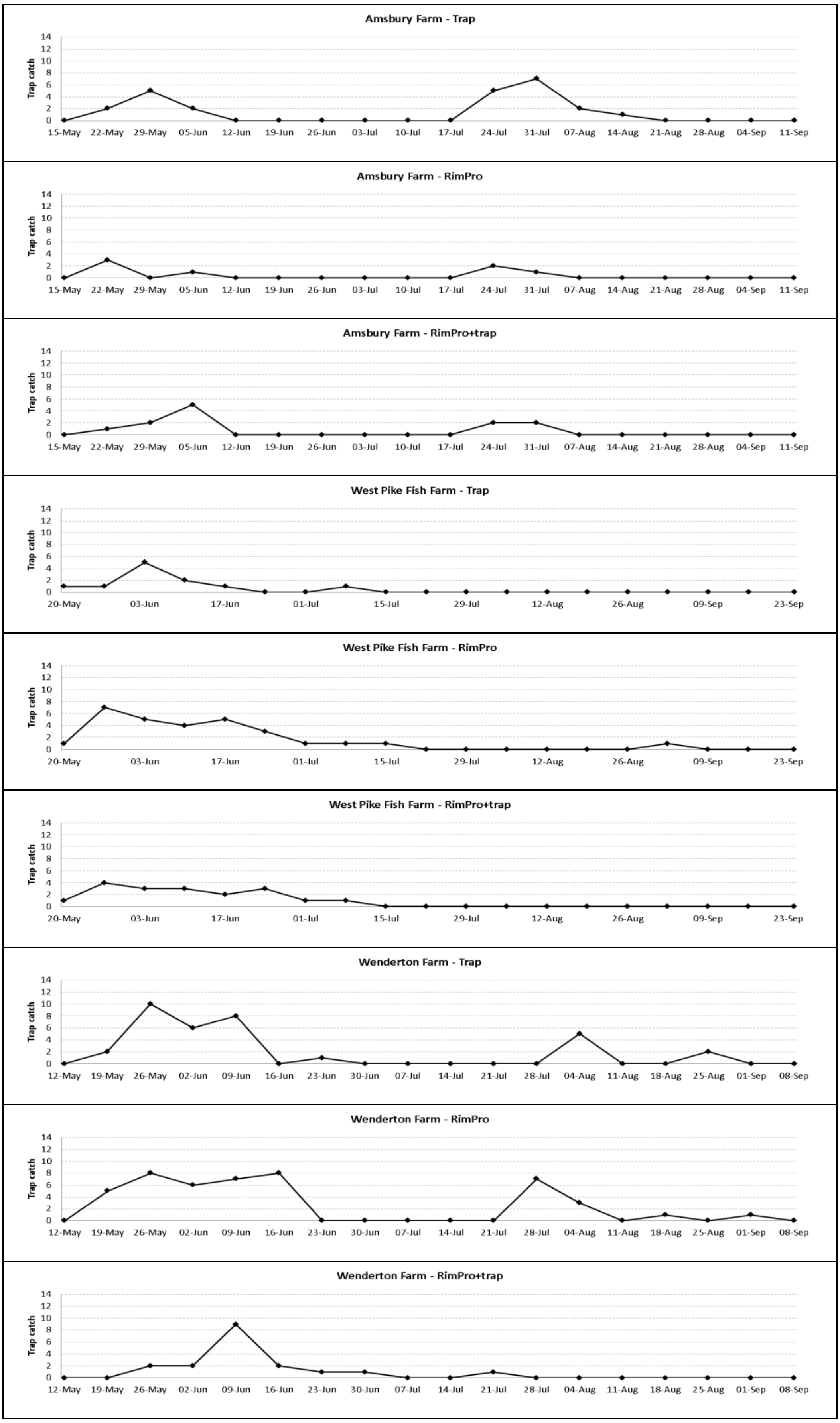

Figure 10. Summer fruit tortrix moth sex pheromone trap catches

Overview of performance of the treatments in the three years of project (2012-2014)

Numbers of insecticides applied for codling moth

The different spray timing methods resulted in grand averages of 1.8, 3.4 and 1.7 insecticide sprays being applied for the Trap, RIMpro and RIMpro+trap treatments, respectively (Table 8). Thus the RIMpro treatment resulted in twice as many spay applications than the other two treatments, which performed similarly. Numbers increased from a grand average 0.6 for the Trap and RIMpro+trap treatments in 2012, to 2-2.3 for these treatments in 2013 and 2014. This doubling was mainly due to the lowering of the pheromone trap threshold, implemented in the second and third year. The numbers of sprays applied in the RIMpro treatment increased from an average of 2.7-3 in 2012 and 2013 to 4.7 in 2014. This increase appeared to be due to a combination of warmer weather in 2014 (2013 was a very late spring) and re-parameterisation of the RIMpro model in the final year. The numbers of sprays for the RIMpro treatment in 2014 would have been even higher had the growers followed the second generation model predictions.

Table 8. Numbers of insecticide sprays applied for codling moth according to treatment in the three years

Site	**Trap**	**RIMpro**	**RIMpro+trap**
		2012	
Amsbury	1	3	1
Pike Fish	1	3	0
Wenderton	0	2	1
		2013	
Amsbury	2	2	2
Pikefish	2	3	2
Wenderton	3	4	3
		2014	
Amsbury	4	4	3
Pikefish	2	5	2
Wenderton	1	5	1
		Average 2012-2014	
Amsbury	2.3	3.0	2.0
Pikefish	1.7	3.7	1.3
Wenderton	1.3	3.7	1.7
Grand average	1.8	3.4	1.7

Codling moth damage to fruit recorded at harvest

The different spray timing methods resulted in grand averages of 3.2, 1.5 and 2.6% damage due to codling moth for the Trap, RIMpro and RIMpro+trap treatments, respectively (Table 9). The damage was consistently highest at Amsbury Farm (Site 1), damage being low at the other two sites, except the trap treatment in 2012, the high (3.33%) damage in that instance prompting the lowering of the trap threshold in the subsequent two years. None of the three treatments met the very high standard of the economic damage threshold of 0.3%, damage being more typically in the range 0.5-1.5%.

Table 9. Codling moth damage to fruit at harvest in each of the three years of the project

Site	Trap no:/ha	%	RIMpro no:/ha	%	RIMpro + trap no:/ha	%
			2012			
Amsbury	22285	16.55	10246	3.62	27597	10.73
Pike fish	3000	0.68	500	0.10	1750	0.48
Wenderton	7950	3.33	1551	0.69	582	0.27
			2013			
Amsbury	6967	2.67	6097	2.95	5497	3.46
Pikefish	2833	1.04	1917	1.91	2583	1.51
Wenderton	213	0.07	853	0.26	853	0.22
			2014			
Amsbury	5141	3.42	2791	3.13	4921	4.40
Pikefish	325	0.66	200	0.44	650	1.48
Wenderton	104	0.29	104	0.40	296	0.96
			Average 2012-2014			
Amsbury	11464	7.50	6378	3.20	12672	6.20
Pikefish	2053	0.80	872	0.80	1661	1.16
Wenderton	2756	1.20	836	0.50	577	0.48
			Grand average			
All three sites	5424	3.19	2695	1.50	4970	2.61

Acknowledgements

Thanks to Clive Baxter, Paul Bennett, Tim Biddlecombe, Alan Burbridge, David Gosling, Mark Holden, Russell Graydon, James Smith, Paul Smith and Marc Trapman for their help with this project. Thanks are also owed to EMR staff for their help with the harvest assessments.