Department
for Environment
Food & Rural Affairs

# Pest specific plant health response plan: *Rhagoletis pomonella* (apple maggot fly)

**Figure 1.** Adult *Rhagoletis pomonella*. © Joseph Berger, Bugwood.org.

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https://planthealthportal.defra.gov.uk/pests-and-diseases/contingency-planning/

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## Contents

# 1. Introduction and scope

1.1. This pest specific response plan has been prepared by the Defra Risk and Policy team. It describes how the Plant Health Service for England will respond if an infestation of *Rhagoletis pomonella* (apple maggot fly) is discovered.

1.2. This document will be used in conjunction with the *Defra Contingency Plan for Plant and Bee Health in England* (https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/593508/generic-contingency-plan-plant-bee-health-england.pdf), which gives details of the teams and organisations involved in pest response in England, and their responsibilities and governance. It also describes how these teams and organisations work together in the event of an outbreak of a plant health pest.

1.3. The aim of this response plan is to facilitate the containment and eradication of *R. pomonella*.

# 2. Summary of threat

2.1. *Rhagoletis pomonella* is native to eastern North America, where its native host is hawthorn (*Crataegus* spp.). Around 160 years ago, the fly moved onto cultivated apples (Walsh, 1867), and was subsequently detected in Oregon, west USA in 1979 (Sansford *et al.*, 2016; Yee *et al.*, 2014). The fly was recorded in Washington in the following year (Brunner, 1987), and in 2006, the fly was recorded in British Columbia in Canada (CABI, 2017). *Rhagoletis pomonella* has now spread across most of the USA, much of Canada and is present locally in Mexico.

2.2. Adult flies puncture the skin of the fruit when laying eggs, and the resulting larvae burrow into the flesh and form irregular tunnels (CABI, 2017). These symptoms reduce the quality of the fruit and impact negatively on yield (Sansford *et al.*, 2016). Additional chemical sprays are used to alleviate these effects in the fly's current range, increasing the cost of production (e.g. Bond *et al.*, 1984). The presence of *R. pomonella* also affects the export of apples and other hosts as a result of rejection or extra measures imposed by other states within a country or by other countries (Sansford *et al.*, 2016).

2.3. Eggs, larvae and adults of *R. pomonella* are mainly associated with apple (*Malus*) fruit, and pupae are generally found in the soil beneath apple trees. Hawthorn (*Crataegus* spp.) is also an important host of the fly, and it has been recorded on a number of other plants in the Rosaceae family, including *Cotoneaster* spp., *Prunus* spp. and *Pyrus* spp. In the UK, the risk of entry is reduced through the prohibition of *Crataegus*, *Malus*, *Prunus*, *Pyrus* and *Rosa* plants for planting from non-European countries, other than dormant plants free from leaves, flowers and fruit (Annex III, EU directive 2000/29/EC). There is also a prohibition on soil from Turkey, Belarus, Moldavia, Russia, Ukraine and third countries not belonging to continental Europe, other than Egypt, Israel, Libya, Morocco and Tunisia (Annex III, EU directive 2000/29/EC). Further, trees and shrubs from third countries, other than European and Mediterranean countries, must come in free from fruit. The pathway of entry is therefore limited to imports of host fruit alone, though this risk is partly mitigated by the need for an inspection in the country of origin for fruit of *Malus*, *Prunus*, *Pyrus* and *Vaccinium*. Fruit and soil moved in passenger baggage and over the internet are also a risk.

2.4. *Rhagoletis pomonella* was intercepted in England with fresh apples from North America on several occasions in the 1920s (Reid and Malumphy, 2009), but it has not been intercepted in recent years.

# 3. Risk assessments

3.1. *Rhagoletis pomonella* has an unmitigated and mitigated UK Plant Health Risk Register score of 60 and 40, respectively. These scores are reviewed as and when new information becomes available (https://secure.fera.defra.gov.uk/phiw/riskRegister/viewPestRisks.cfm?cslref=18132).

3.2. A pest risk analysis for the Washington State Department of Agriculture was carried out to determine the risk of *R. pomonella* entering the pest free area of Washington on municipal green waste, and to recommend risk mitigation options (Sansford *et al.*, 2016).

# 4. Actions to prevent outbreaks

4.1. *Rhagoletis pomonella* is a IAI EU listed pest under non-European Tephritidae.

4.2. *Rhagoletis pomonella* is an A1 listed pest in EPPO region and is therefore recommended for regulation by EPPO member countries.

4.3. The Plant Health Service should be aware of the measures described in this plan and be trained in responding to an outbreak of *R. pomonella*. It is important that capabilities in detection, diagnosis, and risk management are available.

## Prohibitions

4.4. In annex III of the EU directive 2000/29/EC, the following hosts of *R. pomonella* are prohibited from entry into member states:

- Plants of *Crateagus* L., *Malus* Mill., *Prunus* L., *Pyrus* L., and *Rosa* L., intended for planting, other than dormant plants free from leaves, flowers and fruit, from non-European countries (Part A, article 9)

- Plants of *Photinia* Ldl., intended for planting, other than dormant plants free from leaves, flowers and fruit, from the USA, Japan, the Republic of Korea and Democratic People's Republic of Korea (Part A, article 9.1)

- Plants of *Malus* Mill., *Prunus* L., *Pyrus* L. and their hybrids, intended for planting, other than seeds, from non-European countries, other than Mediterranean countries, Australia, New Zealand, Canada, and the continental states of the USA (Part A, article 18)

4.5. There is also a prohibition on soil and growing medium, which consists in whole or in part of soil or solid organic substances such as parts of plants, humus including peat or bark, other than that composed entirely of peat, from Turkey, Belarus, Moldavia, Russia, Ukraine and third countries not belonging to continental Europe, other than Egypt, Israel, Libya, Morocco and Tunisia (Annex III, Part A, article 14).

4.6. However, there is an exception for soil and growing medium intended to sustain the viability of plants from these countries (with the exception of Algeria) as long as the following official statement is given:

a) the growing medium, at the time of planting, was:

- either free from soil, and organic matter, or
- found free from insects and harmful nematodes and subjected to appropriate examination or heat treatment or fumigation to ensure that it was free from other harmful organisms, or
- subjected to appropriate heat treatment or fumigation to ensure freedom from harmful organisms, and

b) since planting:

- either appropriate measures have been taken to ensure that the growing medium has been maintained free from harmful organisms, or
- within two weeks prior to dispatch, the plants were shaken free from the medium leaving the minimum amount necessary to sustain vitality during transport, and, if replanted, the growing medium used for that purpose meets the requirements laid down in (a). (Annex IV, Part A, section I, article 34)

## Plant Requirements

4.7. In annex IV of EU Directive 2009/29/EC, trees and shrubs, intended for planting, other than seeds and plants in tissue culture, originating in third countries other than European and Mediterranean countries, must have an official statement that the plants:

- Are clean (i.e. free from plant debris) and free from flowers and fruits
- Have been grown in nurseries
- Have been inspected at appropriate times and prior to export and found free from symptoms of harmful bacteria, viruses and virus-like organisms, and either found free from signs or symptoms of harmful nematodes, insects, mites and fungi, or have been subjected to appropriate treatment to eliminate such organisms (Part A, article 39)

## Inspections

4.8. In annex V of the EU Directive 2000/29/EC, a plant health inspection is required in the country of origin or the consignor country before being permitted to enter the community for the following hosts of *R. pomonella*:

- Plants, intended for planting, other than seeds but including seeds of *Prunus* L. (Part B, section I, article 1)

- Parts of plants, other than fruits and seeds, of *Prunus* L. and cut flowers of *Rosa* L., originating in non-European countries (Part B, section I, article 2)

- Fruits of:
    - *Malus* Mill., *Prunus* L., *Pyrus* L., and *Vaccinium* L., originating in non-European countries (Part B, section I, article 3)

# 5. Response activities

## Official action to be taken following the suspicion or confirmation of *Rhagoletis pomonella* on imported plants, including fruit

### Holding consignments at interception points, including packhouses

5.1. If *R. pomonella* is suspected by the Plant Health and Seeds Inspectorate (PHSI) to be present in a consignment moving in trade, the PHSI must hold the consignment until a diagnosis is made. Ideally, the consignment should be placed in a sealed cold store and any opened containers should be resealed (which could be via wrapping in plastic if this facility is available). Other consignments that are at risk of cross-contamination should also be held pending a risk assessment on whether cross-contamination has or could have potentially occurred. Samples should be sent to Fera Science Ltd., National Agri-Food Innovation Campus, Sand Hutton, York, YO41 1LZ (01904 462000) in a sealed bag or container, within at least two other layers of containment, which are not liable to be crushed during transit.

5.2. When an infestation of *R. pomonella* is confirmed, the PHSI should advise the client of the action that needs to be taken by way of an official plant health notice. The consignment should be double bagged and destroyed by either incineration or deep burial, or re-exported in a sealed container, ideally triple sealed (unless subjected to treatments in 5.3, which may exempt the consignment from destruction or re-export).

5.3. *Rhagoletis pomonella* can also be killed by cold treatment. For apple and hawthorn, fruit must be maintained at ≤ 0.6°C for a minimum of 42 days or ≤ 3.3°C for a minimum of 90 days (see appendix 3 of Canadian Food Inspection Agency (2017) for further details of cold storage requirements). If this is a feasible option, the use of this method should be discussed with the Risk and Policy team.

5.4. In intercepted inland, any host plants (including any fruit, which should be held) should be surveyed on the site or in the immediate vicinity in the summer (with fruit released if found free) and again in the following year for signs of pest presence (see 5.18-5.20 for sampling details). If the site is in an area where hosts are grown, a buffer zone survey should be established within 1 km of the infested site. This area may be extended depending upon the host distribution in the area. Waste disposal processes and areas should also be inspected to ensure best practice is followed.

5.5. A Europhyt notification should be made upon confirmation of an interception of live *R. pomonella*.

5.6. In the event that all or part of the consignment has not been held and has been distributed to other premises prior to diagnosis, trace forward and trace back inspections should take place upon suspicion or confirmation of *R. pomonella*. Details of recent past and future consignments from the same grower/supplier should also be obtained.

5.7. A pest alert to raise awareness of *R. pomonella* and its symptoms should be distributed to packers/processors and importers where *R. pomonella* has been found, and to those in the local area and those associated with the infested premises. The pest alert can be found on the Plant Health Portal - https://planthealthportal.defra.gov.uk/pests-and-diseases/pest-and-disease-alerts/notifiable-pests/.

## Official action to be taken following the suspicion of a *Rhagoletis pomonella* outbreak

5.8. A Contingency Core Group (CCG), chaired by the Chief Plant Health Officer (CPHO) or their deputy and including specialists from APHA, Defra and other organisations, should be set up to assess the risk and decide on a suitable response at strategic and operation levels. This may include gathering more information on the suspected outbreak, such as the completion of the outbreak assessment, notification of ministers and senior officials, and agreeing a communications strategy. The CCG will also decide who will be the control authority, and the control authority will then nominate an incident commander. An Incident Management Team (IMT) meeting, chaired by the Incident Commander, will subsequently convene to produce an Incident Action Plan (IAP) to outline the operational plan. See the Defra *Generic Contingency Plan for Plant and Bee Health in England* for full details.

5.9. The CCG will set an alert status, which will take into account of the specific nature of the outbreak. Under most scenarios, an infestation of *R. pomonella* suspected in an apple orchard or the wider environment is likely to be given an amber alert status. An amber alert status refers to a serious plant pest/disease with potential for relatively slow, but extensive geographical spread leading to host death and/or major economic, food security or environmental impacts.

### Restrictions on movement of material, equipment and machinery to and from the place of production

5.10. Eggs and larvae of *R. pomonella* are associated with apple fruit. The fruit should therefore be restricted from leaving the site, except for when they are being sent for destruction by deep burial or incineration (see 5.51).

5.11. Larvae and pupae can be transferred in soil associated with non-host material, equipment and machinery, and adults can hitch hike on these. Movement of material, equipment and machinery, which are likely to result in the movement of soil between infested and non-infested areas should therefore be restricted. However, if movement is necessary, the material, equipment and machinery should be thoroughly cleaned at the designated outbreak site to remove any soil and life stage of *R. pomonella*.

5.12. If *R. pomonella* is found in the wider environment, amenity sites and/or private gardens, movement of host material, and used equipment and machinery should be restricted from within at least 100 m of the finding.

### Preliminary trace forward / trace backward

5.13. Information obtained regarding the origins of infested consignments should be used to locate other related and therefore potentially infested consignments. Information should also be obtained on the destination to which suspect consignments have been sent.

5.14. In addition to tracing investigations relating to consignments, trace forward/back investigations linked to machinery used in the infested orchard should also be made.

## Confirming a new outbreak

### How to survey to determine whether there is an outbreak

5.15. Information to be gathered by the PHSI on the suspicion of an infestation of *R. pomonella*, in accordance with ISPM 6; guidelines for surveillance (http://www.acfs.go.th/sps/downloads/13717_ISPM_6_E.pdf):

- The origin of the host fruit and/or trees.
- Details of other premises or destinations where host fruit has been sent, where the fly may be present.
- The layout of the premises and surrounding area (in relation to potential buffer zones), including a map of the fields/cropping/buildings, at risk growers, and details of neighbouring crops, especially any commercial or non-commercial hosts in fields, allotments, gardens or glasshouses.
- Details of the host variety, growth stage and any other relevant information.
- Description of the surrounding habitat, including all hosts e.g. hawthorn in hedgerows.
- Area and level of infestation, including life stages and a description of symptoms (could take photos). Symptoms would include puncture damage on fruit caused by adults, and larval tunnelling within the fruit.
- The location of any known populations, including grid references.
- The date and time the sample was taken, how it was identified and by whom.
- Current treatments/controls in place e.g. chemical treatments.
- Details of the movement of people, equipment, machinery etc. to and from the infested area.
- Cultural and working practices.
- The name, address, email and telephone number of the person who found the pest and/or its symptoms.

5.16. This information should be included on the plant pest investigation template (see Appendix III of the Defra *Generic Contingency Plan for Plant and Bee Health in England*).

5.17. Further to information gathering, samples of other *R. pomonella* infested fruit should be taken to confirm the extent of the infestation e.g. in surrounding orchards. This initial survey will be used to determine if it is an isolated finding or an established outbreak.

5.18. Finance for the surveys will depend on the individual circumstances of the outbreak, and will be subject to discussion, usually between Defra policy and the PHSI.

## Sampling

5.19. When adult *R. pomonella* lay eggs underneath the skin of the fruit, they leave puncture wounds, which can become discoloured around the outside (see Appendix A, symptoms/signs). Suspect fruit can be cut open to inspect for larval tunnelling damage, including fruit which has dropped prematurely.

5.20. Adult flies are small (4-5 mm in length) and are difficult to spot. Trapping is therefore the best option for sampling adults:

- In North America, traps based on visual and olfactory cues are used to detect and control the fruit flies. Visually, there are two main trap designs; yellow fluorescent panels and red spheres. Another type of trap, called the Ladd trap, is composed of a yellow panel with half a red sphere on either side. Olfactory stimuli are added to these visual traps to improve catch rates. These include ammonium carbonate and ammonium acetate, and fruit volatiles. Yellow traps, delta traps and Mcphail traps are sold by Russell IPM. (http://www.russellipm-agriculture.com/portfolio/impact-board-yellow/; http://new.russellipm-agriculture.com/insect.php?insect_id=140&lang=en). Russell IPM also sell an ammonium bicarbonate lure for *R. pomonella*.

- In the general survey of Washington State, USA, the density of yellow panel traps (Pherocon AM) baited with ammonium carbonate is roughly one trap per square mile (Sansford *et al.*, 2016). However, traps are thought to only attract flies within a 2 m radius, so to delimit an area of infestation, a greater trapping density would be required. In Washington, traps are placed on the south facing side under the canopy of trees with fruit (Sansford *et al.*, 2016). They are also changed regularly (e.g. every 4 weeks) (Sansford *et al.*, 2016).

- If yellow panel traps are used, these should be single sided, as they are easier to manipulate in the lab.

5.21. Following the identification/capture of an adult, pupae, larva, and/or larval feeding damage, the samples should be sent for diagnosis as in point 5.1. Each sample should be labelled with full details of sample number, location (including grid reference if possible) and variety.

## Diagnostic procedures

5.22. Morphological diagnosis of *R. pomonella* can only be done for adults. A key for the identification of non-European quarantine fruit flies has been adapted by Dr. Chris Malumphy (Fera Science Ltd.) from White and Elson-Harris (1992). This allows morphological identification to either *R. pomonella* or *Rhagoletis mendax*. *Rhagoletis cornivora*, *Rhagoletis zephyria* and an undescribed species infesting *Cornus florida* (flowering dogwood) are also similar to these species, and may not be able to be differentiated morphologically.

5.23. The first morphological identification would be confirmed by sequencing the sample. However, even sequencing may not be able to differentiate the different species in every case. Therefore, a combination of morphology, sequencing data, host and situation will be used to diagnose *R. pomonella*.

## Criteria for determining an outbreak

5.24. If *R. pomonella* is detected at a location and is not confined to a particular consignment(s) then an outbreak should be declared, such as in an apple orchard or in the wider environment. However, if the finding is restricted to recently imported apples within a cold store or to other recently imported produce or plants, then this would be classified as an interception.

## Official Action to be taken following the confirmation of an outbreak

5.25. The scale of the outbreak will determine the size and nature of the IMT and action.

### Communication

5.26. The IMT will assess the risks and communicate details to the IPPC, EU and EPPO, in accordance with ISPM 17: pest reporting (https://www.ippc.int/en/publications/606/), as well as within Government to Ministers, senior officials and other government departments, devolved authorities, and agencies (e.g., the Environment Agency) on a regular basis as appropriate; and to stakeholders.

### Surveillance and demarcated zones

5.27. After an outbreak has been detected, a demarcated area should be established that includes:

- An infested zone (e.g. the infested orchard). This may also include orchard margins or uncropped areas if the infestation is found on e.g. hedgerow species, such as hawthorn. For a finding in the wider environment, amenity site or private garden, the infested zone should extend out at least 100 m from the finding.

- A buffer zone, which should extend out to at least 1 km from the infested zone, but may extend out further depending on the characteristics of the outbreak.

5.28. Initial maps of outbreak sites should be produced by either the PHSI or the Risk and Policy team.

5.29. All host plants in the buffer zone should be visually inspected and any suspect samples should be sent for diagnosis. Visual and pheromone traps should be used as described in 5.20.

5.30. If it is considered possible that the pest has been spread to distant orchards or other sites (outside of the buffer zone) on machinery or via other human assisted spread, these sites should also be surveyed. If resources are limited, priority should be given to areas where there has been movement of large quantities of soil or fruit from the infested zone. These zones should be treated as if they are part of the buffer zone.

5.31. The demarcated area should be adjusted in response to further findings. If *R. pomonella* is found within an orchard or other site outside the infested zone, this should subsequently be

designated as infested. If flies are found within uncropped areas outside the infested zone, then any orchard directly adjacent to these areas should normally be designated as infested.

## Decontamination procedures

5.32. See point 5.11.

5.33. Any waste (plant or other potentially infested material) should be removed and destroyed (via deep burial, incineration or other appropriate methods, see 5.51).

## Pest Management procedures

**Infested zone**

5.34. Host plants should be treated as soon as possible with a foliar insecticide to knock down the population of *R. pomonella*. The PHSI will advise on an appropriate treatment regime in consultation with the Defra Risk and Policy team. Foliar insecticides can be used to control adults, and systemic foliar insecticides may be effective against larvae inside the fruit. However, foliar insecticides will have no effect on the larvae, pupae or adults within the soil.

5.35. Prior to any insecticides being used, the risk posed by the insecticides to people and the environment will be assessed.

5.36. Growers and landowners will be placed under notice to apply the recommended pesticides and make the applications using their own or contractor's equipment. Records of applications will be kept, including details of the amount of product and water used. It may be necessary to require that organic crops are treated.

5.37. In the case of private householders, officials may agree to organise the application of pesticides, with responsibility for payment of costs remaining with the occupier or other person in charge, or for it to be undertaken by the relevant local authority which will be responsible for determining whether to accept responsibility for the costs of the work or seek recovery. Exceptionally, officials may, in the interests of speed, have to arrange for the work to be carried out and bear the cost, where possible seeking recovery after the event.

5.38. Bee advisors and local beekeepers should be contacted to inform them of any insecticide applications and their timing. Bee inspectors should be able to provide contact details.

5.39. Visual inspections and pheromone traps should be used to assess the efficacy of insecticide treatments.

5.40. All host fruit should be removed, contained on site in sealed containers, ideally within two layers, and destroyed as in 5.51. Alternatively, any apples can be cold treated as in 5.3 and sold or processed (to be discussed with the IMT). This will eliminate egg and larval stages present within the fruit.

5.41. If there is a risk of adults emerging from the soil in the following year, attempts should be made to remove access to host material in the infested zone. These will be discussed by the IMT. Possible options include one or more of the following:

- Removal and destruction of host trees as in 5.51. While this ensures that *R. pomonella* will not have access to host material, this is also the most costly option to the grower and may only be applicable to a small number of trees.

- Removal of fruit from host trees and/or cut trees back early in spring the following year and/or thinning, prior to the emergence of larvae from fruit.

- Covering of trees with fine netting. This may only be applicable to a small number of trees.

- Covering the ground to prevent the emergence of *R. pomonella* and/or agitation of soil in the infested area.

5.42. Other host trees, such as those in uncropped areas, orchard boundaries and hedgerows, should also be subject to one of the options in 5.41 depending on the circumstances of the outbreak.

**Measures to be taken in the case of detection of infestation in apples after harvest in an orchard (e.g. during processing/packaging and grading)**

5.43. The following should be designated as infested:

- The lot from which the sample was taken.
- The waste from the infested lot, such as processed waste.
- The equipment and other articles (e.g. machinery and packing material) which have been in contact with the lot.
- The orchard where the lot was grown.

5.44. As in point 5.27, a buffer zone should be created that extends out to at least 1 km from the infested orchard(s) and store.

5.45. Orchards or areas where potentially infested equipment, waste, and other articles, have been used should be surveyed, and any host fruit harvested from these orchards should be inspected.

5.46. Points 5.2 – 5.4 and 5.6 – 5.7 should be followed, but only destruction and cold treatment rather than re-export should be considered.

5.47. There is the risk that other host fruit stocks may have become infested after harvest (cross contamination). Any host fruit in storage should therefore be inspected for symptoms and for the presence of *Rhagoletis pomonella*.

5.48. Refer to the 5.34-5.42 should *R. pomonella* be found in an orchard.

**Crops growing within the buffer zone (at least 1 km around the infested zone) in the year of the outbreak**

5.49. If no infestation is found in host trees growing in the buffer zone following surveillance, then they should be treated with a programme of foliar insecticides under notice (if appropriate) until harvest/fruit fall and monitored for any sign of *R. pomonella*. Monitoring should include the use of pheromone traps.

5.50. Apples (and other host fruit) should be inspected during and/or immediately after harvesting if on an orchard site, and if *R. pomonella* is not found, fruit is free to be moved.

## Disposal plan

**Infested trees and harvested fruit/soil/plant debris**

5.51. All stages may be present with the harvested fruit, associated soil and plant debris. It is important that all of this material is disposed of safely so as to eliminate the pest. When deciding on the most appropriate method(s) of disposal, factors such as the likelihood of adults being present, the level of handling and transportation required, all need to be taken into account. For all methods, measures need to be taken to ensure that there is no risk of spread during transport and treatment or disposal. Material that can be moved safely should be destroyed by incineration at a licensed facility (if in small quantities) or deep burial. Disposal and/or destruction should be under the approval and supervision of the PHSI. If the material has to be moved off the premises, it should be contained within at least one sealed layer, and two layers if possible. Deep burial may be done at an approved landfill site, on the site or nearby, but only in agreement with the local Environment Agency. Incineration must comply with appropriate waste management regulations, Environment Agency in England, Scottish Environment Protection Agency and Natural Resources Wales.

5.52. All objects designated as 'infested', such as equipment, machinery, storage facilities that may be contaminated with infested soil or plant material should be thoroughly cleansed to remove the pest and all soil. This should be carried out at the outbreak site or a site nearby in agreement with a Plant Health and Seeds Inspector. Any waste material generated should be bagged and sent for deep burial or incineration (as in 5.51).

# Measures in subsequent seasons

## Infested zone

5.53. If there is a risk of the presence of *R. pomonella* in the soil following use of one of the options in point 5.41, then these options should be continued for at least 5 years (under notice) due to the potential for the fly to remain dormant in the soil for that length of time, and due to its ability to disperse locally in search of host plants.

5.54. Trap crops may also be used in the years following the outbreak. These should be treated regularly with insecticide and the host fruit destroyed later in the season well before they would usually begin to drop off the tree (as the fly can lead to premature fruit drop and may exit the fruit prior to fruit drop).

5.55. Any host plants should be inspected regularly during spring and summer, and, if appropriate, sprayed with an appropriate insecticide program as discussed with the Risk and Policy team. Pheromone traps should also be used.

5.56. The frequency of inspections and insecticidal sprays will be determined by the IMT.

### Buffer zone

5.57. Host plants should be inspected regularly (including the use of pheromone traps) during spring and summer, and, if appropriate, sprayed with an appropriate insecticide program as discussed with the Risk and Policy team. This should be carried out for at least 5 years in line with the infested zone.

5.58. The frequency of inspections and insecticidal sprays will be determined by the IMT.

# 6. Criteria for declaring eradication / change of policy

6.1. A *R. pomonella* outbreak can be declared eradicated (by the CPHO) only after five years during which time no *R. pomonella* life stages have been found.

# 7. Evaluation and review of the contingency plan

7.1. The *Defra Generic Contingency Plan for Plant and Bee Health in England* requires that the pest specific plan is reviewed following an outbreak. This pest specific contingency plan should also be reviewed annually to take into account of changes in legislation, control procedures, pesticides, sampling and diagnosis methods, and any other relevant amendments.

7.2. Lessons should be identified during and after any *R. pomonella* or non-*R.pomonella* outbreak, including what went well and what did not. These should be included in any review of the contingency plan leading to continuous improvement of the plan and response to outbreaks.

# 8. Appendix A

## Data sheet for *Rhagoletis pomonella*

### Identity

| PREFERRED SCIENTIFIC NAME | AUTHOR (taxonomic authority) |
|---|---|
| *Rhagoletis pomonella* | (Walsh, 1867) |

CLASS: Insecta
ORDER: Diptera
SUBORDER: Brachycera
SUPERFAMILY: Tephritoidea
FAMILY: Tephritidiae
SUBFAMILY: Trypetinae

SYNONYMS

*Rhagoletis symphoricarpi* Curran
*Spilographa pomonella* (Walsh)
*Trypeta pomonella* Walsh
*Zonosema pomonella* (Walsh)

COMMON NAMES

Æbelflue (Danish)
Apple fruit fly (English)
Apple maggot (English)
Apple maggot fly (English)
Railroad worm (English)
Larve de la pomme (French)
Mouche de la pomme (French)
Apfelfliege (German
Apfelfruchtfliege (German)
Mosca delle mele (Italian)
Epleflue (Norwegian)
Mosca de las manzanas (Spanish)
Äpplefluga (Swedish)

### Notes on taxonomy and nomenclature

*Rhagoletis pomonella* is one of four closely related species in the *Rhagoletis pomonella* species group, which are separated based on their allozyme frequencies (Berlocher *et al.*, 1993). These species include *Rhagoletis cornivora*, *R. mendax* and *R. zephyria*. The *Rhagoletis pomonella* species group also contains one host race or undescribed species that infests *Cornus florida* (flowering dogwood) (Berlocher *et al.*, 1993).

## Biology and ecology

### Life history

*Rhagoletis pomonella* is separated into different host races, including apple and hawthorn races, and adult flies of different host races will emerge at different times during the summer in line with the availability of their preferred host (Smith, 1988; Feder *et al.*, 1993, 1994, 1998; Feder, 1995). Adults live for up to 40 days and feed on a variety of food sources, including insect honeydew and bird dung (Christenson and Foote, 1960; Sansford *et al.*, 2016; CABI, 2017). They generally require 7-10 days to reach sexual maturity, when they then begin to mate (CABI, 2017). Females choose their mate based upon a male courtship dance and non-volatile aromatic hydrocarbon pheromones emitted by the males (Garman, 1937; Milne and Milne, 1980; Arnett, 1985). Adult females lay eggs singly beneath the skin of the fruit, and can lay as many as 200 eggs in their lifetime (CABI, 2017).

Larvae hatch within 3-10 days and burrow into the pulp of the fruit, where they feed from two weeks to several months depending on their host; larvae feed for longer in winter apples (EPPO, 2017). The infested fruit will generally drop to the ground, where the larvae will exit the fruit and enter the soil at a depth of 2-5 cm to pupate (CABI, 2017). Larval emergence from the fruit may continue until early December (CABI, 2017). The prepupal period lasts from two to 18 hours (Sansford *et al.*, 2016). *Rhagoletis pomonella* usually exhibits a univoltine life cycle, but there are occasions where adult emergence will occur in the same year as diapause initiation, giving rise to a partial second generation. There are also some individuals that will not eclose from pupae for two to four years, or after 5 years (EPPO, 2017; Yee, personal communication, 2017 referring to Mailloux (1967)).

## Hosts/crops affected

The most significant host of *R. pomonella* is apple (*Malus domestica*), which the fly moved onto following the introduction of apple into the USA in the 1600s. Previously, the natural host was considered to be *Crataegus* spp. (hawthorn). *Rhagoletis pomonella* has also been recorded from other fruit crops, such as other *Malus* spp., *Prunus* spp., *Pyrus* spp., and *Vaccinium corymbosum*, as well as wild plant species in the family Rosaceae, such as *Amelanchier*, *Aronia*, *Contoneaster* spp., *Rosa* spp. and *Sorbus* spp. Although, the fly being recorded from these species does not necessarily imply completion of the lifecycle. The full list of plants on which *R. pomonella* has been recorded from are shown in table 1.

**Table 1.** Host plants of *Rhagoletis pomonella*.

| Host plant | Type | Reference |
|---|---|---|
| ***Amelanchier* (serviceberries)** | Wild/weed | CABI (2017); EPPO (2017) |
| ***Amelanchier bartramiana*** | | Yee *et al.* (2014) |
| ***Aronia* (chockeberry)** | Wild/weed | CABI (2017) |
| ***Cornus florida* (flowering dogwood)** | Wild/weed | CABI (2017) |
| ***Cotoneaster*** | Wild/weed | CABI (2017); EPPO (2017) |
| ***Cotoneaster apiculatus* (cranberry cotoneaster)** | Other | CABI (2017) |
| ***Cotoneaster coriaceus*** | Other | CABI (2017) |
| ***Cotoneaster integerrimus* (European cotoneaster)** | Other | CABI (2017) |
| ***Cotoneaser lacteus* (smooth hawthorn)** | Other | Yee and Goughnour (2008) |
| ***Crataegus* (hawthorns)** | Wild/weed | CABI (2017); EPPO (2017) |
| ***Crataegus aestivalis* (eastern mayhaw)** | | Yee *et al.* (2014) |
| ***Crataegus brachyacantha* (blueberry hawthorn)** | | Yee *et al.* (2014) |

| | | |
|---|---|---|
| ***Crataegus brainerdii* (Brainerd's hawthorn)** | | Yee *et al.* (2014) |
| ***Crataegus crus-galli* (cockspur hawthorn)** | Wild/weed | CABI (2017) |
| ***Crataegus cuprina*** | | Yee *et al.* (2014) |
| ***Crataegus douglasii* (black hawthorn)** | Wild/weed | CABI (2017) |
| ***Crataegus erythropoda* (cerro hawthorn)** | | Yee *et al.* (2014) |
| ***Crataegus flabellata* (fan-leaf hawthorn)** | | Yee *et al.* (2014) |
| ***Crataegus flava* (yellowleaf hawthorn)** | | Yee *et al.* (2014) |
| ***Crataegus gracilior*** | | Yee *et al.* (2014) |
| ***Crataegus greggiana* (Gregg's hawthorn)** | | Yee *et al.* (2014) |
| ***Crataegus holmesiana* (Holmes' hawthorn)** | | Yee *et al.* (2014) |
| ***Crataegus laevigata* (smooth hawthorn)** | Wild/weed | CABI (2017) |
| ***Crataegus invisa*** | | Yee *et al.* (2014) |
| ***Crataegus macracantha* (long-thorned hawthorn)** | | Yee *et al.* (2014) |
| ***Crataegus macrosperma* (bigfruit hawthorn)** | | Yee *et al.* (2014) |
| ***Crataegus marshallii* (parsley hawthorn)** | | Yee *et al.* (2014) |
| ***Crataegus mexicana* (manzanita tejocotera)** | | Yee *et al.* (2014) |
| ***Crataegus mollis* (downy, red hawthorn)** | Other | CABI (2017) |
| ***Crataegus monogyna* (hawthorn)** | Wild/weed | CABI (2017) |
| ***Crataegus opaca* (riverflat hawthorn)** | | Yee *et al.* (2014) |
| ***Crataegus pedicellata* (scarlet hawthorn)** | | Yee *et al.* (2014) |
| ***Crataegus pruinosa* (waxyfruit hawthorn)** | | Yee *et al.* (2014) |
| ***Crataegus punctata* (dotted hawthorn)** | | Yee *et al.* (2014) |
| ***Crataegus rivularis* (river hawthorn)** | | Yee *et al.* (2014) |
| ***Crataegus rosei*** | | Yee *et al.* (2014) |
| ***Crataegus suksdorfii* (Suksdorf's hawthorn)** | Other | CABI (2017) |
| ***Crataegus viridis* (green hawthorn)** | | Yee *et al.* (2014) |
| ***Malus* (ornamental species apple)** | Other | CABI (2017) |
| ***Malus baccata* (Siberian crab apple)** | Other | CABI (2017) |
| ***Malus domestica* (apple)** | Main | CABI (2017); EPPO (2017) |
| ***Photinia melanocarpa* (black chokeberry)** | | Yee *et al.* (2014) |
| ***Photinia pyrifolia* (red chokeberry)** | | Yee *et al.* (2014) |
| ***Prunus* (stone fruit)** | Wild/weed | CABI (2017); EPPO (2017) |
| ***Prunus americana* (American plum)** | Other | CABI (2017); EPPO (2017) |
| ***Prunus angustifolia* (mountain cherry tree)** | Other | CABI (2017) |
| ***Prunus armeniaca* (apricot)** | Other | CABI (2017); EPPO (2017) |
| ***Prunus avium* (sweet cherry)** | Other | CABI (2017); EPPO (2017) |
| ***Prunus cerasifera* (myrobalan plum)** | Other | CABI (2017) |
| ***Prunus cerasus* (sour cherry)** | Other | CABI (2017); EPPO (2017) |
| ***Prunus domestica* (European plum)** | Other | CABI (2017) |
| ***Prunus emarginata* (bitter cherry tree)** | Other | CABI (2017) |
| ***Prunus mahaleb* (mahaleb cherry)** | Other | CABI (2017) |
| ***Prunus persica* (peach)** | Other | CABI (2017) |
| ***Prunus salicina* (Japanese plum)** | Other | CABI (2017) |
| ***Prunus umbellate* (hog plum)** | | Yee *et al.* (2014) |
| ***Prunus virginiana* (common chokecherry tree)** | Other | CABI (2017) |
| ***Pyracantha angustifolia* (narrowleaf firethorn)** | | Yee *et al.* (2014) |
| ***Pyracantha coccinea* (scarlet firethorn)** | Other | CABI (2017) |
| ***Pyrus communis* (European pear)** | Other | CABI (2017) |
| ***Pyrus pyrifolia* (Oriental pear tree)** | Other | CABI (2017) |
| ***Pyrus serotina* (Asian pear)** | Other | Yee and Goughnour (2006) |
| ***Rosa* (roses)** | Wild/weed | CABI (2017); EPPO (2017) |
| ***Rosa rugosa* (rugose rose)** | Other | CABI (2017) |
| ***Rosa virginiana* (Virginia rose)** | Other | CABI (2017) |
| ***Sorbus aucuparia* (European mountain ash)** | Other | CABI (2017) |
| ***Sorbus scopulina* (Greene's mountain ash)** | Other | CABI (2017) |
| ***Vaccinium corymbosum* (blueberry)** | Other | CABI (2017) |

## Plant stage affected

*Rhagoletis pomonella* affects the plant during fruit production.

## Plant parts affected

Fruit.

## Symptoms/signs - description

Adult flies leave oviposition punctures on the surface of the fruit, which appear sunken and discoloured around the outside (Figure 2; CABI, 2017).

Larvae burrow into the flesh of the fruit and leave irregular tunnels, which turn brown (Figure 2; CABI, 2017). As infestation progresses, fruit can become distorted, and in severe cases, become brown rotten masses (Weems and Fasulo, 2015). The fruit may also drop prematurely (Weems and Fasulo, 2015).

**Figure 2.** Oviposition punctures, tunnelling and misshapen apple fruit caused by larvae of *R. pomonella*. © Dr Y. Wee.

## Morphology

**Egg:** Elliptical, creamy white, and about 0.9 mm long and 0.23 mm wide. The egg is semi-opaque and is more opaque and more yellow at the ends.

**Larva:** Legless, and creamy white or yellowish in colour. When fully grown, it is 6.5 – 12 mm long and 1.5 – 2 mm wide. The body is tapered towards the head and separated into 11 segments (see Figure 3).

**Pupa:** Oval, yellow to brown in colour, and roughly 5 mm long and 2.3 mm wide (see Figure 4).

**Adult:** Small (4 – 5 mm long), with a black body and yellow/orange head and legs, and greenish eyes. Males have three white horizontal bands on the abdomen, while females have four. Each wing has four irregular black bands, of which three converge to form an ‘F’ shape (see figure 1).

**Figure 3.** *Rhagoletis pomonella* larva. © Dr Y. Wee

**Figure 4.** *Rhagoletis pomonella* pupae. © Dr Y. Wee.

## Similarities to other species/diseases/plant damages

*Rhagoletis pomonella* is one of four closely related species in the *Rhagoletis pomonella* species group, and is difficult to distinguish morphologically from *Rhagoletis cornivora*, *R. mendax* and *R. zephyria* (Berlocher *et al.*, 1993). The *Rhagoletis pomonella* species group also contains one host race or undescribed species that infests *Cornus florida* (flowering dogwood) (Berlocher *et al.*, 1993).

Damage caused by *R. pomonella* could also be confused with the damage of other pests of apple, including *Cydia pomonella* (codling moth) (Figure 5), *Hoplocampa testuclinea* (apple sawfly) (Figure 6), *Ametastegia glabrata* (dock sawfly) (Figure 7) and *Rhynchites aequatus* (Rhynchites weevil) (Figure 8). Larvae in all four of these species bore into the apple fruit and leave tunnels. Adult feeding damage by *R. aequatus* can also leave distinctive holes in the fruit as shown in Figure 8, which resemble the punctures caused by *R. pomonella* during oviposition. Holes created by leaf rolling caterpillars like *Archips podana* (fruit tree tortrix), *Adoxophyes orana* (summer fruit tortrix), *Epiphyas postvittana* (light brown apple moth) and *Blastobasis decolorella* may also resemble puncture wounds of *R. pomonella*, but significant tunnelling does not occur.

**Figure 5.** *Cydia pomonella* larva and the tunnels it has left in an apple. © RHS

**Figure 6.** *Hoplocampa testudinea* larvae and tunnelling within an apple. © RHS

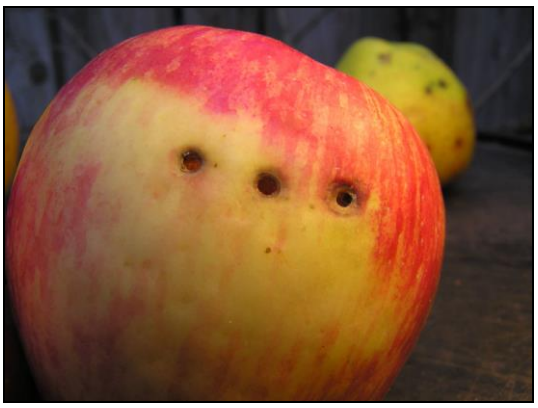

**Figure 7.** *Ametastegia glabrata* damage on apple. Ontario Ministry of Agriculture Food and Rural Affairs. © Queen's Printer for Ontario, 2009. Reproduced with permission.

**Figure 8.** *Rhychites* damage to gala apples. © NIAB EMR

## Detection and inspection methods

Fruit can be visually inspected for oviposition punctures and discolouration, including fruit which has dropped prematurely (Figure 2).

*Rhagoletis pomonella* seeks food sources and host fruit using visual and olfactory cues (CABI, 2017). In North America, traps based on these cues are used to detect and control the fruit flies. Visually, there are two main trap designs; yellow fluorescent panels, which are used to mimic supernormal foliage, and red spheres, which are used to mimic host fruit. Red spheres generally catch more flies than yellow panels (e.g. Prokopy and Hauschild, 1979; Rull and Prokopy, 2003), but are more difficult to handle in the field, making yellow traps the preferred option for detection in a number of cases (Sandsford *et al.*, 2016; Yee and Goughnour, 2011). There are a number of yellow trap types and Yee and Goughnour (2011) have shown that they differ in their effectiveness in attracting *R. pomonella*, likely because of a combination of their particular shade of yellow and amount of fluorescence. Another type of trap, called the Ladd trap, is composed of a yellow panel with half a red sphere on either side. While this trap outcompeted yellow panels in a study by Rull and Prokopy (2003), they suffer from the same constraints as red spheres in that they are difficult to handle and position, and are also expensive.

Olfactory stimuli are added to these visual traps to improve catch rates. To mimic food sources, protein odours, such as ammonium carbonate and ammonium acetate, are used (CABI, 2017). These have been effective in the west of the USA (Jones and Davis, 1989; Yee *et al.*, 2006, 2014). While to mimic host sources, fruit volatiles, generally in the form of short chain carbon esters, are used. Butyl hexanoate alone has been effective (Reynolds and Prokopy, 1997; Rull and Prokopy, 2000; Morrison *et al.*, 2016), as have blends of several esters. One particular blend consisting of butyl butanoate, propyl hexanoate, butyl hexanoate, hexyl butanoate and pentyl hexanoate has proven to be as or more attractive than butyl hexanoate alone (Stenliski and Liburd, 2002; Zhang *et al.*, 1999). Like with protein odours, the effectiveness of fruit volatiles seems to depend on location. So far, they have only been effective in the east of the USA. The reason for this different preference between the east and west is not clear, but could be due to race differences between the flies.

## Distribution

**Table 2. Distribution of *Rhagoletis pomonella*.**

| (P) present, (W) widespread, (L) localized, (O) occasionally present, (D) reported in the past, no longer present, (E) eradicated, (I) absent, intercepted only | | |
|---|---|---|
| **COUNTRY/REGION** | **DISTRIBUTION** (see codes above) | **REFERENCES**: please write (name, date) citation here and include full bibliographic details in reference list |
| **ASIA** | Absent | |
| **AFRICA** | Absent | |
| **NORTH AMERICA** | P | |
| **CANADA** | L | Yee *et al.* (2014) |
| Alberta | O | Yee *et al.* (2014) |
| British Columbia | O | Yee *et al.* (2014) |
| Manitoba | L | Yee *et al.* (2014) |
| New Brunswick | W | Yee *et al.* (2014) |
| Nova Scotia | P | Yee *et al.* (2014) |
| Ontario | W | Yee *et al.* (2014) |
| Prince Edward Island | W | Yee *et al.* (2014) |
| Québec | W | Yee *et al.* (2014) |
| Saskatchewan | L | Yee *et al.* (2014) |
| **MEXICO** | L | Yee *et al.* (2014) |
| **USA** | W | EPPO (2017) |
| Arizona | P | Yee *et al.* (2014) |
| Arkansas | Absent | Yee *et al.* (2014) |
| California | W | Yee *et al.* (2014) |
| Colorado | W | Yee *et al.* (2014) |
| Connecticut | W | Yee *et al.* (2014) |
| Delaware | P | Yee *et al.* (2014) |
| Florida | L | Yee *et al.* (2014) |
| Georgia | P | Yee *et al.* (2014) |
| Idaho | P | Yee *et al.* (2014) |
| Illinois | W | Yee *et al.* (2014) |
| Indiana | W | Yee *et al.* (2014) |
| Iowa | P | Yee *et al.* (2014) |
| Kansas | P | Yee *et al.* (2014) |
| Maine | P | Yee *et al.* (2014) |
| Maryland | P | Yee *et al.* (2014) |
| Massachusetts | W | Yee *et al.* (2014) |
| Michigan | W | Yee *et al.* (2014) |
| Minnesota | P | Yee *et al.* (2014) |
| Mississippi | P | Yee *et al.* (2014) |
| Missouri | P | Foote *et al.* (1993) |
| Montana | P | Yee et al. (2015) |
| Nebraska | P | Yee *et al.* (2014) |
| New Hampshire | W | Yee *et al.* (2014) |
| New Jersey | W | Yee *et al.* (2014) |
| New York | W | Yee *et al.* (2014) |
| North Carolina | W | Yee *et al.* (2014) |
| North Dakota | P | Yee *et al.* (2014) |
| Ohio | P | Yee *et al.* (2014) |
| Oregon | W | Yee *et al.* (2014) |
| Pennsylvania | P | Yee *et al.* (2014) |
| Rhode Island | P | Yee *et al.* (2014) |
| South Carolina | P | Yee *et al.* (2014) |

| | | |
|---|---|---|
| South Dakota | P | Yee *et al.* (2014) |
| Texas | W | Yee *et al.* (2014) |
| Utah | W | Yee *et al.* (2014) |
| Vermont | W | Yee *et al.* (2014) |
| Virginia | P | Yee *et al.* (2014) |
| Washington | P | Yee *et al.* (2014) |
| West Virginia | P | Yee *et al.* (2014) |
| Wisconsin | W | Yee *et al.* (2014) |
| Wyoming | P | Hood *et al.* (2013) |
| **CENTRAL AMERICA & THE CARIBBEAN** | Absent | |
| **SOUTH AMERICA** | Absent | |
| **EUROPE** | Absent | |
| **OCEANIA** | Absent | |

## History of introduction/spread

*Rhagoletis pomonella* is native to east USA, where it shifted from hawthorn (*Crataegus* spp.) to cultivated apples around 150 years ago (Walsh, 1867). Likely as a result of being introduced with infested apples, the fly was first detected in Oregon, west USA, in 1979 (Sansford *et al.*, 2016; Yee *et al.*, 2014). The fly was recorded in Washington in the following year (Brunner, 1987), and in 2006, the fly was recorded in British Columbia in Canada (CABI, 2017). *Rhagoletis pomonella* is currently spread across the USA, much of Canada and is localised in Mexico (Table 2).

## Phytosanitary status

*Rhagoletis pomonella* is a IAI EU listed pest under non-European Tephritidae. It is also on several other phytosanitary lists (table 3).

**Table 3.** Global phytosanitary categorization of *Rhagoletis pomonella*.

| Country/NPPO/RPPO | List | Year of addition |
|---|---|---|
| **AFRICA** | | |
| East Africa | A1 list | 2001 |
| Southern Africa | A1 list | 2001 |
| **AMERICA** | | |
| Argentina | A1 list | 1995 |
| Brazil | A1 list | 1992 |
| Canada | A2 list | 1989 |
| Chile | A1 list | 1992 |
| Paraguay | A1 list | 1992 |
| Uruguay | A1 list | 1992 |
| **ASIA** | | |
| Bahrain | A1 list | 2003 |
| China | A2 list | 1993 |
| Jordan | Quarantine pest | 2007 |
| Kazakhstan | A1 list | 2009 |
| Uzbekistan | A1 list | 2008 |
| **EUROPE** | | |
| Azerbaijan | A1 list | 2007 |
| Belarus | Quarantine pest | 1994 |
| Moldova | A1 list | 2006 |
| Norway | Quarantine pest | 2012 |
| Russia | A1 list | 2014 |

| | | |
|---|---|---|
| Turkey | A1 list | 2007 |
| Ukraine | A1 list | 2010 |
| **OCEANIA** | | |
| New Zealand | Quarantine pest | 2000 |
| **RPPO** | | |
| APPPC | A1 list | 1993 |
| COSAVE | A1 list | 1992 |
| EPPO | A1 list | 1975 |
| OIRSA | A1 list | 1992 |

## Means of movement and dispersal into the UK

Adult flies generally disperse locally within, or close by to, orchards (Neilson, 1971). Although they are capable of flights greater than 1 km (CABI, 2017; Maxwell and Parsons, 1968; Roitberg *et al.*, 1984), there is no evidence of long distance natural spread that would allow dispersal from North America into the UK. Instead, the main pathway is likely to be via human transport, principally the movement of eggs and larvae in infested fruit on either plants for planting or as produce. Pupae of *R. pomonella* can also be transferred in soil.

## Control

### Cultural controls and sanitary methods

#### *Resistance*

There are no examples of resistance in apple, except for in the *Malus* hybrid E36-7. While the hybrid was susceptible to larval feeding during September and October, it was impervious to larval feeding during the summer in eastern USA (Myers *et al.*, 2008). Rull and Prokopy (2004) have also shown that *R. pomonella* exhibits a preference for certain apple genotypes. Host location in *R. pomonella* is partly governed by olfactory cues, and such a preference may therefore stem from the distinct cocktail of volatiles emitted from the host fruit of different genotypes. It is also hypothesised that the physical and chemical properties of the fruit itself may deter alighting flies. Pree (1977) showed, for example, that resistance in some crabapple varieties was correlated with total phenol content, and that supplementing the diet of *R. pomonella* with phenolic acids, gallic, tannic and o-coumaric acids, quercetin, naringen and d-catchin, inhibited larval development.

#### *Hygiene*

Good hygiene should include the destruction of fallen and infested apples (CABI, 2017). Wild and abandoned host trees in the vicinity of the orchard may also be destroyed (CABI, 2017), but given that *R. pomonella* can disperse several hundred meters in search of new hosts (e.g. Maxwell and Parsons, 1968), this may only be partially effective.

#### *Treatments of growing crop*

Surround (kaolin clay or aluminium silicate hydroxide) treatments controlled *R. pomonella* to a degree that was equivalent to the chemicals, azinphosmethyl and spinosad, in a study by Villanueva and Walgenbach (2007). Surround also reduced oviposition in *Rhagoletis indifferens* and *Rhagoletis mendax* (Lemoyne *et al.*, 2008; Yee, 2008). Such efficacy has been attributed to several mechanisms. Firstly, the white colour of the substance acts as a visual deterrent, reducing

the number of flies alighting on Surround covered trees (Leskey *et al.*, 2010; Villanueva and Walgenbach, 2007). Secondly, Surround acts as a tactile deterrent, reducing residence time, resting and foraging (Leskey *et al.*, 2010). And finally, Surround affects survival of *R. pomonella*, reducing it by ~12 days, possibly because of the substance attaching to the flies' mouthparts and blocking the uptake of food and water (Leskey *et al.*, 2010). Other explanations of reduced survival include the blocking of sphericals important for respiration, and desiccation (Leskey *et al.*, 2010).

***Treatments of harvested fruit***

Quarantine treatments to avoid the spread of *R. pomonella* in harvested apple have traditionally either involved cooling fruit to 0°C for 40 days (Weems and Fasulo, 2015; Yee *et al.*, 2013). Further treatments also show promise, including the use of a high $CO^2$ atmosphere, irradiation, low pressure and the use of other fumigants, such as chloropicrin, Telone II, and Chloropicrin + Telone II (Agnello *et al.*, 2002; Hallman, 2004; Hulasare *et al.*, 2013; Yee *et al.*, 2013).

## Biological control

While there are currently no effective commercial biological control agents against *R. pomonella*, there are a number of naturally occurring insects and pathogens in North America that may help to suppress *R. pomonella* populations. These include the wasps, *Biosteres melleus*, *Diachasma alloeum*, *Opius downesi*, *Opius melleus*, *Patasson conotrachelli* and *Pteromalus* sp., which were shown to parasitise either eggs or larvae (Brunner and Klaus, 1993; Stelinski *et al.*, 2010; Weems and Fasulo, 2015). With the exception of *D. alloeum*, these wasps are considered to be ineffective against *R. pomonella* feeding in apple; for *B. melleus*, *O. downesi* and *Pteromalus* sp., this was attributed to the short length of their ovipositors (Brunner and Klaus, 1993). Even so, they may have a role in parasitising *R. pomonella* on other hosts in the wider environment. The density of the field crickets, *Gryllus pennsylvanicus* and *Nemobius fasciatus*, in an orchard was also shown to be correlated with the mortality of *R. pomonella* in a study by Monteith (2012), who subsequently demonstrated that the crickets consumed pupae in a simulated natural environment. In addition, the bacterium, *Serratia marcescens*, was shown to kill adult flies, and the fungi, *Beauveria bassiana* and *Metarhizium robertsii*, were demonstrated to infect both larvae and adults (Lauzon *et al.*, 2003; Muniz-Reyes *et al.*, 2014).

## Field monitoring/economic threshold levels

Kairomone baited traps are used to monitor for *R. pomonella* (see Detection and inspection methods section). Accurate economic threshold levels have not been developed, even in areas long known to have the pest, and instead growers generally treat the crop 7-10 days after the first fly is caught (Brunner and Klaus, 1993; Weems and Fasulo, 2015). Growers then spray every 10-21 days while the fly is active or until flies are no longer being caught in traps (Brunner and Klaus, 1993; Weems and Fasulo, 2015).

Trapping can also be used as a control method, rather than just for monitoring. Traps covered with a sticky substance and a bait can be used as part of an attract and kill strategy. They can even be effective when just placed around the perimeter of an orchard; in Quebec, for instance, traps baited with butyl hexanoate placed around the perimeter of apple orchards gave 99.5-100% control (Bostanian *et al.*, 1999). Although, if traps are only to be placed around the perimeter, it is important to ensure that no flies are already present within the orchard.

### Chemical control

*Rhagoletis pomonella* is primarily controlled using a programme of foliar applied insecticide treatments. These are mainly used to control adults, as eggs and larvae, and pupae, are protected in the fruit and soil, respectively. Although, it is possible to target the eggs and larvae inside fruit using a systemic insecticide. Organophosphates, such as dimethoate and azinphosmethyl, are effective against *R. pomonella* (CABI, 2017; Duan and Prokopy, 1995), but there are also a number of other effective chemicals available, including imidacloprid, thiacloprid, abamectin, thiamethoxam, indoxacarb, spinosad and chlorantraniliprole (Hu *et al.*, 2000; Pelz *et al.*, 2005; Reissig, 2003; Teixeira *et al.*, 2008). Apart from the organophosphates, imidacloprid and abamectin, these chemicals are approved for use on apple in the UK (Health and Safety Executive, 2017). Soil applications of insecticides may also be used against pupae, but these may provide inadequate protection and may not be approved for use in the UK (CABI, 2017). It should be noted that foliar insecticide programmes already used to control other pests, such as the codling moth, may also provide some control of *R. pomonella*. So far, there has been no evidence of resistance to chemical pesticides in *R. pomonella*, and there is little evidence of resistance in the majority of tephritid flies (Yee, personal communication, 2017).

These sprays have traditionally been used across the whole orchard (cover sprays), but there is evidence that just spraying the perimeter of the orchard can provide equivalent control and reduce spraying costs (Trimble and Solymar, 1997; Trimble and Vickers, 2000). As for perimeter trapping, this should only be used when *R. pomonella* has not been detected within the orchard (Trimble and Vickers, 2000). It should also be considered along with other pests, which may increase in importance if a cover spray is not used (Trimble and Vickers, 2000).

A more specific means of targeting *R. pomonella* using insecticides has been developed using insecticide baited traps in an attract and kill strategy. While traps can simply be employed using a sticky surface, they can quickly become covered in insects, reducing their effectiveness. These traps can be redeployed, but this is labour intensive (Prokopy *et al.*, 1990). Spinosad has been shown to be an effective insecticide when used in a trap set up; in a study by Pelz *et al.* (2005), spinosad (used in the formulation GF-120) reduced the number of *R. pomonella* by 67% compared with the control over a six week period. Imidacloprid (Hu *et al.*, 2000; Stelinski *et al.*, 2001), thiamethoxam (Stelinski *et al.*, 2001) and dimethoate (Duan and Prokopy, 1995; Hu *et al.*, 2000) have also shown good efficacy. One issue with insecticide treated traps is that rain can wash off the insecticide, meaning the insecticide has to be reapplied frequently. One potential solution is the addition of paraffin wax, which was shown to increase rainfastness of GF-120, and outperformed GF-120 alone in field trials (though it was not significantly better than the control) (Teixeira *et al.*, 2009). Another potential solution is the use of a controlled release contour cap system for spinosad, which sustained lethality under simulated rainfall analogous of what would be experienced by apple orchards in the northeast of USA (Wright *et al.*, 2012).

## Phytosanitary measures

See section 4 of the contingency plan.

## Impacts

### Economic impact

Due to the symptoms caused by *R. pomonella* in fruit, yield and quality is reduced (Sansford *et al.*, 2016). In a 10 year study, the fly reduced crop yield by 16.9% annually in Quebec in a non-treated apple orchard (Vincent and Bostanian, 1988). To alleviate the effects of *R. pomonella*, chemical sprays are used in the US, increasing the cost of production. Bond *et al.* (1984) estimated that the total cost of spraying for the fly in apple, sweet cherry and tart cherry would have been $356,596 in Utah in 1984, assuming that all commercial orchards in the state were significantly affected to have needed chemical treatment.

The presence of *R. pomonella* may also incur export production costs as a result of quarantine regulations enacted by other states within a country or by other countries (Sansford *et al.*, 2016). This possibility was investigated by Bond *et al.* (1984) in Utah, who estimated losses of > $1 million per year due to quarantine restrictions from California, who receive 30-40% of Utah apples, and the subsequent need to dump the fruit in the local market. Another report has indicated that the overall domestic and export cost of *R. pomonella* could be $392.5 million annually in Washington should the fly continue to spread (Community Attributes Inc., 2017).

In the UK, apples from 2011-2015 valued at £583 million, while other hosts, such as pears, plums and cherries valued at £69, 58 and 45 million, respectively, over the same period. If *R. pomonella* has impacts similar to that in the US, significant losses, in the millions, could occur.

### Environmental impact

*Rhagoletis pomonella* is considered to be native to wild hawthorn (*Crataegus* spp.), but has also been recorded on other plants that are present in the wild or in a non-commercial setting, including apple (*Malus* spp.), pear (*Pyrus* spp.) and *Cotoneaster*. It therefore has the potential to alter the biodiversity associated with these plants through competition, as a food source, and hybridization. The latter, for example, has been indicated between *R. pomonella* and *R. zephyria* in the Pacific Northwest (McPheron, 1990).

The insecticides used against *R. pomonella* may also have a significant effect on non-target arthropods, including pollinators and natural enemies, as well as birds and water bodies.

### Social impact

Although there are few records of social impacts, as many of the hosts of *R. pomonella* are present in gardens, there is potential for the fly to become a problem pest for gardeners.

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