Department
for Environment
Food & Rural Affairs

Pest specific plant health response plan:

Outbreaks of rose rosette virus (RRV) and its vector *Phyllocoptes fructiphilus*

Figure 1. Reddened shoots on a rose, caused by an infection of RRV. Courtesy of Patrick Di Bello, Oregon State University.

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Executive summary

Background	
Regulation	GB Quarantine pest
Key Hosts	Roses
Distribution	Canada, India, USA
Key pathways	Plants for planting
Industries at risk	Rose growers
Symptoms (5.21-5.23)*	• Leaf symptoms – red colouration, distortion, leaf mosaic, and abnormal leaf proliferation • Stem and branch symptoms – witches' broom, red pigmentation, stunting, excessive thorniness, dieback of shoots, and distortion • Flowering symptoms – reduced flowering, distortion, phyllody, and discolouration
Surveillance	
Demarcated zones	Infected zone = ≤ 200 m Buffer zone ≤ 1 km
Surveillance activities (5.17-5.20)	Visual surveys in infested and buffer zones
Response measures	
Interceptions (5.1-5.5)	Destruction is via deep burial or incineration. Tracing exercises are carried out where required and an UKPHINs notification should be made. Further surveillance of the area for inland findings.
Outbreaks (5.45-5.52)	• Sampling and destruction of infested material • The movement of hosts, plant products and soil into and out of the infested zone should be restricted • Restrictions on the movement of machinery and equipment • Treatments with foliar acaricides • Monitoring of infested area for regrowth which should be removed and destroyed
Key control measures	
Biological	N/A
Chemical	Foliar acaricides, herbicides
Cultural (5.12-5.14)	• Avoiding the use of leaf blowers • Working from healthy areas to infected areas • Clean tools and equipment regularly • Pruning • Removing fallen debris.
Declaration of eradication	
Eradication can be declared if no pest is detected during annual surveys for at least two years after the date of the last finding	

* Numbers refer to relevant points in the plan

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 rose rosette virus (RRV) and/or its main vector *Phyllocoptes fructiphilus* is discovered in *Rosa* spp.

1.2. The plant health authorities in Northern Ireland, Scotland, Wales and the Crown Dependences have been consulted on this plan and will use it as the basis for the action they will take in the event of RRV and/or *P. fructiphilus* being detected in their territories.

1.3. This document will be used in conjunction with the *Defra Contingency Plan for Plant Health in England* - https://planthealthportal.defra.gov.uk/assets/uploads/Generic-Contingency-Plan-for-Plant-Health-in-England-FINAL-2.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.

1.4. The aims of this response plan are to facilitate the containment and eradication of RRV and/or *P. fructiphilus* and to make stakeholders aware of the planned actions and statutory requirements pre and post border.

2. Summary of threat

2.1. RRV is an emaravirus believed to be native to the eastern Rocky Mountains on *Rosa woodsii* (Martin, 2013). It was first reported in Manitoba, Canada, in 1940, and shortly after in California and Wyoming, USA (Conners, 1941, as cited by Pemberton *et al.*, 2018; EPPO, 2018). Over the next few decades, the virus spread across the Midwest and south, and by 1996, had spread as far east as Maryland, Ohio, Pennsylvania, Tennessee and West Virginia (Amrine, 2002; Tipping and Sindermann, 2000). More recently, RRV has been reported in Florida (2013), Ontario (2014), Louisiana (2015) and Minnesota (2017), indicating that the virus is still spreading in North America (Babu *et al.*, 2014; Bratsch *et al.*, 2017; EPPO, 2018; EPPO Reporting Service, 2017b; Morgan *et al.*, 2015). RRV was also found outside North America for the first time in two ornamental gardens in West Bengal, India, in 2017, following a survey of rose diseases (Charkaborty *et al.*, 2017; EPPO Reporting Service, 2017a).

2.2. *Phyllocoptes fructiphilus* was first reported from California, USA, from its native host *Rosa californica*, and has since been found in a number of other US states (EPPO, 2020b; Stevens *et al.*, 2020). The recorded distribution of the mite does not fully correspond with the distribution of the virus, but this is likely to be due to the mite

being underreported because eriophyoid mites are difficult to detect and identify (EPPO, 2018; Stevens *et al.*, 2020).

2.3. Both RRV and *P. fructiphilus* are only known to occur on *Rosa* spp. and their cultivars (Amrine, 2002; EPPO, 2018; Epstein and Hill, 1999). While there are *Rosa* spp. and cultivars which have been observed to be less susceptible and even reported to be resistant in some cases, resistance to the virus and the mite has not yet been confirmed in these species (EPPO, 2018). All *Rosa* spp. and cultivars are therefore considered to be susceptible to RRV and *P. fructiphilus* (EPPO, 2018).

2.4. The expression of RRV symptoms is highly variable and dependent on the species and cultivar of rose, the age and growth stage of the plant, the climate, and the stage of disease progression (EPPO, 2018). Symptoms observed on leaves include red colouration, distortion, leaf mosaic, and abnormal leaf proliferation (Babu *et al.*, 2015; Diakaki *et al.*, 2019; EPPO, 2018); symptoms observed on stems and branches include witches' broom, red pigmentation, shortened internodes, excessive thorniness, and distortion (Anthony, 2013; Babu *et al.*, 2015; Epstein and Hill, 1999; Hong *et al.*, 2012; Roebuck, 2001; Ward and Kaiser, 2012; Windham *et al.*, 2014) and symptoms observed on flowers include reduced flowering, distortion, phyllody (abnormal development of leafy structures from floral parts), and discolouration (Anthony, 2013; Baker *et al.*, 2014; Hong *et al.*, 2012).

2.5. RRV reduces flowering and the aesthetic appearance of roses, and can kill infected plants within 1-5 years of symptom development (EPPO, 2018). Rose rosette disease progression is usually faster in younger, smaller plants, with infected seedlings often dying within a year, single crowned plants dying within 2-3 years, and parts of multi-crowned plants surviving for up to 5 years (Anthony, 2013). The damage caused by RRV has had adverse economic impacts to the rose industry, commercial landscapes and botanic gardens in the USA (Conner and Hagan, 2012; Ward and Kaiser, 2012). As an example, Fort Worth Botanic Garden in Texas had to remove all of their roses because of the disease (Pope, 2019). Although there are few reports of the mite having impacts on its own, it is also considered to cause damage to roses at high population densities (EPPO, 2018).

2.6. The main pathways for long distance spread of both the mite and virus are the movement of plants for planting and cut flowers of *Rosa* spp. (EPPO, 2018). These two pathways are regulated from Canada, India, Mexico and the USA under current legislation, and help reduce the likelihood of entry of RRV and *P. fructiphilus* into the UK. Locally, the mite disperses primarily in air currents, but it could also move between plants that are in direct contact (EPPO, 2018; Sabelis and Bruin, 1996, as cited by EPPO, 2018). Other means of spread are speculated, including dispersal on insects, such as bees and aphids (phoresy); on tools, equipment and clothes; and by rain and water splash (EPPO, 2018). RRV can also be transmitted by grafting (Amrine *et al.*, 1988, as cited by Anthony, 2013; Anthony, 2013; Doudrick,

1986), and possibly by vegetative propagation (Baker *et al.*, 2014, as cited by EPPO, 2018).

2.7. As of February 2022, there have been no interceptions or outbreaks of RRV or *P. fructiphilus* in the UK, and there have been no interceptions in the EU.

3. Risk assessments

3.1. RRV and *P. fructiphilus* both have an unmitigated and mitigated UK Plant Health Risk Register score of 36 and 24, respectively. Overall scores range from 1 (very low risk) to 125 (very high risk). These scores are reviewed as and when new information becomes available (https://planthealthportal.defra.gov.uk/pests-and-diseases/uk-plant-health-risk-register/viewPestRisks.cfm?cslref=25108 and https://planthealthportal.defra.gov.uk/pests-and-diseases/uk-plant-health-risk-register/viewPestRisks.cfm?cslref=10001).

3.2. Pest risk analyses have been carried out for EPPO, New Zealand and the UK (Anthony, 2013; EPPO, 2018; Tuffen, 2016).

3.3. It is very likely that RRV and the mite could establish in the EPPO region and the UK (EPPO, 2018; Tuffen, 2016). Impacts of the virus in its current range, and the potential impacts in the EPPO region and the UK, are also considered to be high and potentially very high in certain parts of the EPPO region (EPPO, 2018; Tuffen, 2016).

3.4. The pest risk analysis carried out for New Zealand considered RRV in isolation, without the introduction of *P. fructiphilus* (Anthony, 2013). The analysis considered the likelihood of establishment and spread of RRV to be moderate if native vectors were present and very low if they were not present. Economic impacts were considered to be low to moderate, environmental impacts were considered to be negligible, and social impacts were considered to be low at a national level.

4. Actions to prevent outbreaks

4.1. RRV and *P. fructiphilus* is listed in Schedule 1 of The Plant Health (Phytosanitary Conditions) (Amendment) (EU Exit) Regulations 2020. Schedule 1 is the list of GB quarantine pests that are absent from GB and as such they are prohibited from being introduced into, moved within or held, multiplied or released into GB. Further pest and host specific requirements are listed in Schedule 7. RRV and *P. fructiphilus* are GB Priority Pests meaning they are GB quarantine pests which has been assessed to have the most severe potential economic, environmental and social impacts to GB.

4.2. RRV and *P. fructiphilus* are EPPO A1 listed pests and are therefore recommended for regulation by EPPO member countries (EPPO, 2020a, b).

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 RRV and/or *P. fructiphilus*. It is important that capabilities in detection, diagnosis, and risk management are available.

5. Response

Official action to be taken following the suspicion or confirmation of RRV and/or *P. fructiphilus* on imported plants and cut flowers

5.1. If RRV and/or *P. fructiphilus* are suspected by the Animal and Plant Health Agency, Plant Health and Seeds Inspectorate (APHA 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 of host plants of significance 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 Plant Clinic, Fera Science Ltd., York Biotech Campus, Sand Hutton, York, YO41 1LZ (01904 462000) in a sealed crush proof container, within at least two other layers of containment.

5.2. When a finding of RRV and/or *P. fructiphilus* 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, deep burial or another approved method, or re-exported in a sealed container. The method will be chosen on a case-by-case basis.

5.3. If *P. fructiphilus* is intercepted inland and there is the potential for spread from the imported consignment, host plants at risk of contamination should be surveyed on the site and again in the following year for signs of the presence of RRV or *P. fructiphilus*. When the site is in an area where hosts are grown, the survey should include an area extending to 1 km from the affected site. The size of the survey area will be influenced by the local climatic and meteorological conditions, and the density of host crops. The timing and methodology of the survey(s) should also take into account the incubation period of RRV, which is reported to vary from a few weeks to over a year, as visual inspection may not pick up early infections of RRV.

Waste disposal processes should also be agreed to ensure best practice is followed.

5.4. If all or part of the consignment has been distributed to other premises prior to diagnosis, trace forward and trace back inspections should take place upon suspicion or confirmation of RRV and/or *P. fructiphilus*. Details of recent past and future consignments from the same grower/supplier should also be obtained for tracing purposes.

5.5. A pest factsheet to raise awareness of RRV and *P. fructiphilus* and their symptoms should be distributed or recommended to importers where RRV and/or *P. fructiphilus* have been found, and, where suitable, to those in the local area and those associated with the affected premises. The pest factsheet can be found on the Plant Health Portal - https://planthealthportal.defra.gov.uk/pests-and-diseases/pest-and-disease-factsheets/notifiable-diseases/.

Official action to be taken following the suspicion of a RRV and/or *P. fructiphilus* outbreak

5.6. Suspected outbreaks will be assessed on a case by case basis. An Outbreak Triage Group (OTG), 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. The OTG will also decide who will be the control authority (likely the APHA in this case), and the control authority will then nominate an incident commander. An Incident Management Team (IMT) meeting, chaired by the Incident Controller, will subsequently convene to produce an Incident Action Plan (IAP) to outline the operational activities. See the Defra *Generic Contingency Plan for Plant Health in England* for full details.

5.7. The OTG will set an alert status, which will consider the specific nature of the outbreak. These alert levels, in order of increasing severity, are white, black, amber and red (more details on these levels can be found in table 2 of the Defra Generic Contingency Plan for Plant Health in England). Under most scenarios, a suspected outbreak of RRV and/or *P. fructiphilus* is likely to be given an amber alert status, which is used for a serious plant pest/disease that has the potential for relatively slow but extensive geographic spread leading to host death and/or major economic, food security or environmental impacts. However, this could be downgraded to a white alert status (limited geographic spread) in the absence of *P. fructiphilus*.

Restrictions on movement of plants and plant products, equipment, machinery and personnel to and from the affected area

5.8. RRV and *P. fructiphilus* are associated with plants for planting and flowers of their host plants. These should be prevented from leaving the affected area, other than under a statutory plant health notice for destruction by deep burial, incineration or another approved method.

5.9. Movement of material, equipment and machinery, which may result in the movement of life stages of *P. fructiphilus* between infested and non-infested areas, should also be restricted. However, if movement is necessary, the material, equipment and machinery should be thoroughly cleaned at the designated outbreak site to remove any life stage of *P. fructiphilus*.

5.10. Movement of people into the affected area should be severely restricted, especially during the early investigation phase and/or if *P. fructiphilus* is detected. Personnel should be briefed on the importance of good hygiene practice to reduce the risk of carrying life stages of *P. fructiphilus* to other areas of the site or to other sites.

5.11. As a minimum, the affected area should cover the site of the finding (e.g. the nursery, garden centre, botanic garden) or if RRV and/or *P. fructiphilus* is found in the wider environment, the affected area should extend out at least 200 m from the finding.

Preliminary trace forward / trace backward

5.12. If an infested consignment or plant is considered as being the source of the suspect outbreak, investigatios regarding the origins of infested consignments will be undertaken to locate other related and therefore potentially infested consignments moving to and from the site. If applicable the relevant NPPO should be contacted. For findings in the wider environment, where no trace forward or backward can be done, the most likely source should be identified and investigated.

5.13. In addition to tracing investigations relating to consignments, trace forward/back investigations linked to equipment and machinery used in the affected area should also be made if *P. fructiphilus* is present or is suspected to be present in the outbreak site.

General biosecurity advice and advisory measures for growers

5.14. Staff should be trained to monitor rose plants and identify symptoms of RRV and *P. fructiphilus*.

5.15. The spread of *P. fructiphilus* should be reduced by;

- avoiding the use of leaf blowers that may spread the mite,
- working from healthy areas to infected areas,
- cleaning tools and equipment regularly to remove any life stages of the mite, and changing clothes when visiting new areas Tools and equipment could also be separated, with certain tools and equipment only used in particular areas,
- reducing mite populations by pruning in late winter, and removing and destroying fallen foliar material , and
- removing fallen debris.

5.16. Volunteer host plants, *Rosa* weeds and *Rosa* in hedgerows may act as reservoirs for RRV and *P. fructiphilus*. Controlling these plants within and around the affected area reduces the chance of rose plants becoming infected and reduces the risk of survival and persistence of the pests in the event of an outbreak. Volunteer plants and weeds can be controlled mechanically (e.g. hoeing), chemically (e.g. herbicides), and manually (e.g. rogueing).

Confirming a new outbreak

How to survey to determine whether there is an outbreak

5.17. Information to be gathered by the PHSI on the suspicion of an infestation of RRV and/or *P. fructiphilus*, in accordance with ISPM 6; guidelines for surveillance (https://www.ippc.int/en/publications/615):

- The origin of the host plants and associated pathways.
- Details of other premises or destinations where the host plants/products have been sent, where RRV and/or *P. fructiphilus* 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 glasshouses.
- Details of the host variety, growth stage and any other relevant information.
- Description of the surrounding habitat, including main crops and predominant hosts.
- Area and level of infestation, including life stages and a description of symptoms (photos should be taken).
- The locations where RRV and/or *P. fructiphilus* have been detected, including grid references.
- The date the sample was taken, and by whom.
- Current treatments/controls in place e.g. chemical treatments and biological control agents being used.

- Details of the movement of people, equipment, machinery etc. to and from the infested area.
- Cultural, biosecurity and working practices.
- The name, address, email and telephone number of the person who found the pest and/or its symptoms, and the business owner.

5.18. This information should be included on the plant pest investigation template

5.19. Further to information gathering, samples of other affected plants should be taken to confirm the extent of the outbreak e.g. in nearby growing areas. This initial survey will be used to determine if it is an isolated finding or an established outbreak.

5.20. 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.

Inspection and sampling

5.21. Rose plants can be visually examined for symptoms of RRV, which include:

- Leaf symptoms – red colouration, distortion, leaf mosaic, and abnormal leaf proliferation.
- Stem and branch symptoms – witches' broom, red pigmentation, stunting, excessive thorniness, dieback of shoots, and distortion.
- Flowering symptoms – reduced flowering, distortion, phyllody, and discolouration.

These symptoms are described in more detail in Appendix A.

5.22. Symptoms are most evident when the host plant is in active growth and tender shoots are most abundant. In the field, this is likely to be in the spring, while in glasshouses, this may be prior to harvest. However, there are some symptoms, such as witches' broom and excessive thorniness, which are more obvious in winter when the foliage is not present.

5.23. Because symptoms of the virus are not characteristic during the early stages of infection and can be confused with herbicide damage, environmental factors, and other pathogens, the identity of RRV should be confirmed using molecular testing.

5.24. Visual inspection for *P. fructiphilus* is more difficult owing to the small size of the mite and its tendency to coexist with other mites on the same rose plant. Detection and identification is generally only possible using a microscope, either on plant samples or following extraction. Visual inspection is therefore not recommended for mites in the field, but samples sent in with RRV symptoms should be checked for the mite in an official laboratory.

5.25. Trapping can also be used for sampling eriophyoid mites, such as *P. fructiphilus*, including the use of sticky tape for active movement, and sticky glass slides, greased plates, water traps, spore traps and mite collector traps, for passive aerial dispersal. Trapping, extracting and examining the mites is likely to require a lot of resources, however, as numerous mite species will be caught in the traps. Therefore, trapping may not be a practical option.

5.26. Following the capture/putative identification of RRV and/or *P. fructiphilus*, samples should be sent for confirmatory diagnosis as in point 5.1. Each sample should be labelled with full details of the sample number, location (including grid reference if possible), variety, and suspect pest.

Diagnostic procedures

5.27. On arrival to the laboratory, samples will initially be screened for the presence of RRV using real-time qPCR (Taqman). Assays have been developed by Babu *et al.* (2016), the Plant Health and Environmental Laboratory (PHEL) in New Zealand (Vazquez-Iglesias *et al.* 2020a) and by Vazquez-Iglesias *et al.* (2020b). A confirmatory diagnosis will be carried out using reverse transcription PCR (RT-PCR) or high throughput sequencing (Fox *et al.*, 2018). Protocols for RT-PCR have been developed by Dobhal *et al.* (2016) and Di Bello *et al.* (2018), as cited by Diakaki *et al.* (2019).

5.28. Confirmation based on RT-PCR could give results within a week. While, confirmation based on high throughput sequencing could give results within 10 days to two weeks.

5.29. Morphological identification of *P. fructiphilus* is based on a suite of morphological characters including the ornamentation of the prodorsal shield of the protogynes, which is complex and allows for differentiation from other mite species that are found on rose plants (Kiefer, 1940, as cited by Diakaki *et al.*, 2019).

5.30. The mite can also be identified molecularly by comparing the ITS1 sequence to other mite species (Kumar, 2001, as cited by Diakaki *et al.*, 2019). Further work may be required, however, to validate this method and assess whether it is practical.

Criteria for determining an outbreak

5.31. If RRV and/or *P. fructiphilus* is detected at a port or confined to a particular consignment with no risk of spread, then an outbreak should not be declared. If it is found to have spread or likely to have spread beyond its original consignment, for example across multiple lots in a nursery or across multiple beds in a botanic garden, then an outbreak should be declared.

5.32. RRV in the absence of *P. fructiphilus* has limited potential for spread; outbreaks of RRV alone should therefore be managed locally on a case by case basis. If *P. fructiphilus* is found or is suspected, official action should be taken as below.

Official Action to be taken following the confirmation of an outbreak

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

Communication

5.34. The IMT will assess the risks and communicate details to the IPPC 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 administrations, and agencies (e.g., the Environment Agency) on a regular basis as appropriate; and to stakeholders.

5.35. A pest factsheet to raise awareness of RRV and *P. fructiphilus* and its symptoms should be distributed or recommended to importers where RRV and/or *P. fructiphilus* has been found, and, where suitable, to those in the local area and those associated with the affected area. The pest factsheet can be found on the Plant Health Portal - https://planthealthportal.defra.gov.uk/pests-and-diseases/pest-and-disease-factsheets/notifiable-diseases/.

5.36. Information on the outbreak will also be communicated to affected residents and businesses outside the infected zone as appropriate using various media formats e.g. leaflets, official posters, articles in local newspapers, appropriate websites, local radio etc.

5.37. When an outbreak is considered likely to have a limited public impact, APHA media and communication teams will coordinate external communications. An example of such a scenario would be an outbreak in a nursery in a rural location. If the outbreak occurs in an area that is likely to cause significant media and public interest, for example a specialist rose grower, a public park or botanic garden with a high density of roses, then external communications will be coordinated through the Defra Press Office. In all cases, the Defra Press office must be kept informed of the current status of the outbreak and any action taken.

5.38. Depending on the scale and circumstances of the outbreak, a public meeting may be required to inform the local residents and relevant stakeholders of the surveillance and eradication programme.

5.39. A communication plan could involve the following:

- Frequently Asked Questions: a Q&A will be developed for staff as a reference source for questions considered likely to be asked by the media and members of the public. A version of the document for public dissemination will be made available electronically via the appropriate website.
- Lines to take: outlining the main messages that should be put across to the public.
- Stakeholder/message matrix: the Stakeholder/message matrix sets out the list of stakeholders likely to be affected by any outbreak, the order in which they should be contacted, the timescale and method for contacting them, and who they should be contacted by.

Demarcated zones and surveillance

5.40. Once an outbreak has been confirmed, a demarcated area should be established that includes:

- A defined infected zone, which should extend out to at least 200 m from the finding of RRV and/or *P. fructiphilus*. If RRV and/or *P. fructiphilus* is found in a plant nursery, botanic garden or other defined premise, across which spread could have occurred due to management practices, the infected zone may include the whole site.

- A buffer zone, which should extend out to at least 1 km from the infected zone, but may extend out further. The size of the buffer zone will be influenced by the local climatic and meteorological conditions, and the density of host crops. The buffer zone may include other premises in which staff/growers have visited or worked in, premises in which stock has been sent or received, and/or any other premises where there is a perceived risk.

5.41. Initial maps of the outbreak sites should be produced by officials.

5.42. All host plants in the infected and buffer zones, including *Rosa canina* where possible, should be surveyed for RRV and/or *P. fructiphilus*, and symptomatic plants sent in for diagnosis, as described in points 5.21 – 5.26. Because of the long incubation period of RRV, which has been reported to be from a few weeks to over a year, asymptomatic sampling is also recommended.

5.43. Further general surveys will be carried out on hosts grown outside of the buffer zone, as *P. fructiphilus* has the potential for long distance spread. These general surveys could be informed by RHS members and the general public.

5.44. The demarcated area should be adjusted in response to further findings. If RRV and/or *P. fructiphilus* are found in roses outside of the infected zone, an infected

zone should be established extending out at least 200 m from the finding and the buffer zone changed accordingly.

5.45. Surveys will be carried out annually for at least two years after the year of the outbreak to cover the long incubation period of RRV. Symptoms are also not as pronounced early on in infection. Surveys outdoors should be performed during spring or summer when symptoms are more apparent and should ideally cover all rose plants, including those in private gardens, the wider environment and commercial premises.

5.46. If eradication is considered possible following surveillance and information gathering in the year of the finding, pest management procedures should be followed as set out in this contingency plan. If eradication is not considered possible in the year of the finding or in subsequent years, management should move to containment, with actions to be decided by the IMT.

Pest Management procedures

Restrictions

5.47. Host plants or arisings should not be moved out of the demarcated area, with the exception of plants being moved for destruction under statutory plant health notice.

5.48. Movement of material, equipment and machinery, which may result in the movement of life stages of *P. fructiphilus* between infested and non-infested areas, should also be restricted. However, if movement is necessary, the material, equipment and machinery should be thoroughly cleaned at the designated outbreak site to remove any life stage of *P. fructiphilus*.

Infected zone

5.49. All host plants in the infected zone should be treated as soon as possible with a foliar acaricide. Recommendations will be made on an appropriate acaricide treatment regime in consultation with the Defra Risk and Policy team. Table 1 in Appendix A provides a list of acaricides approved for use in the UK as of 14th September 2020. Prior to any acaricides being used, the risk posed by the acaricides to people and the environment will be assessed.

- Prior to any pesticides being used, the risk posed by the pesticide to people and the environment will be assessed.

- Any applications should be made following the advice on the product label and be in accordance with HSE guidance. In some cases, there may be a requirement to carry out a Local Environment Risk Assessment for Pesticides (LERAP) depending on the product used and the situation of the finding

- If there is a finding within a SSSI, Natural England should be contacted to assess the threat of the pesticide application to the site.

- If the situation demands it, it may be necessary to require the use of acaricides even for growers where only biological control agents are being used.

- Growers will be placed under notice to apply the recommended acaricides 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 use.

- Although the mite will be difficult to control using acaricides because of its cryptic lifecycle, they have been recommended by a number of authors and could be used to knock down the mite (e.g. Baker *et al.*, 2014; Singh *et al.*, 2018). Good coverage of the rose plants is advised.

5.50. Following acaricide use, all host plants should be removed and destroyed by deep burial, incineration or another approved method. It is important that the whole plant is removed, including the roots, to minimise regrowth (Hand, 2014). Herbicides should then be used to ensure that any remaining material does not grow up again (EPPO, 2018). Care should also be taken when removing the plant to avoid spreading the mite vector to other roses. Precautions could include bagging the infected plants, destroying plants as soon as possible, and destroying the plants in the affected area where feasible.

5.51. Ideally, all plants, or a representative sample of plants, should be tested for RRV and checked for *P. fructiphilus* before destruction to provide information on the extent of the outbreak. If there are further findings of RRV and/or *P. fructiphilus*, the demarcated area should be adjusted accordingly.

5.52. There may be exceptional circumstances, such as in the case of botanical collections, where plants are managed in a different way to ensure highly valued plants/cultivars are retained. In these circumstances, management methods will be agreed by the IMT.

5.53. In the two years following the year of the finding, areas where rose plants have been removed should be monitored for regrowth, and any regrowth should be removed, tested and destroyed as appropriate.

5.54. No *Rosa* spp. should be replanted in the infected zone until RRV and/or *P. fructiphilus* have been declared eradicated.

Buffer zone

5.55. If RRV and/or *P. fructiphilus* are not found in host plants growing in the buffer zone following surveillance, they should continue to be monitored for symptoms. A programme of foliar acaricides is also advised, but not statutory. The programme of foliar acaricide treatments should be within legally specified safe use guidelines and compatible, where possible, with any existing biological control programmes.

5.56. Monitoring and advisory treatments should continue in the two years following the year of the finding. Surveys should be carried out as described in point 5.42.

Disposal plan

5.57. When deciding on the most appropriate method(s) of disposal, several factors need to be taken into account, such as the likelihood of *P. fructiphilus* being present, the level of handling and transportation required, and the climatic conditions. For all methods, measures need to be taken to ensure that there is no risk of spread during transport, treatment or disposal. This may include keeping the distance of travel to a minimum. Material that can be moved safely should be destroyed by incineration at a licensed facility (if in small quantities) or by deep burial. Disposal and/or destruction should be under the approval of the PHSI through a statutory plant health notice, with any supervision decided on a case-by-case basis. If the material has to be moved off the premises, it should be contained within at least two layers if possible, and placed in a sealed vehicle for transport. Deep burial may be done at an approved landfill site, on the outbreak site or another suitable site nearby, but only in agreement with the local Environment Agency. Incineration must comply with appropriate waste management regulations i.e. as specified by the Environment Agency in England.

5.58. Other viable methods of destruction should be agreed by the IMT.

5.59. All objects designated as ‘infested’, such as equipment, machinery, storage facilities that may be contaminated with *P. fructiphilus* should be thoroughly cleansed to remove the pest e.g. using water under high pressure. This should be carried out in the affected area 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, incineration or another approved method.

6. Criteria for declaring eradication / change of policy

6.1. RRV and/or *P. fructiphilus* can be declared eradicated (by the Chief Plant Health Officer) if they have not been found for at least two years after the date of the last finding.

7. Evaluation and review of the contingency plan

7.1. This pest specific contingency plan should be reviewed regularly in order to consider any 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 outbreak (of RRV, *P. fructiphilus* or any other pest), 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 rose rosette virus and its vector *Phyllocoptes fructiphilus*

Identity

PREFERRED SCIENTIFIC NAME	AUTHOR (taxonomic authority)
Rose rosette emaravirus	ICTV
Phyllocoptes fructiphilus	Kiefer, 1940

Rose rosette emaravirus

KINGDOM: Orthornarvirae
PHYLUM: Negarnaviricota
CLASS: Ellioviricetes
ORDER: Bunyavirales
FAMILY: Fimoviridae
GENUS: Emaravirus

SYNONYMS
Rose rosette virus
RRV

COMMON NAMES
Rose rosette disease
вирус мелколистности розы (Russian)
вирус розеточности розы (Russian)

Phyllocoptes fructiphilus

KINGDOM: Metazoa
PHYLUM: Arthropoda
CLASS: Arachnida
ORDER: Trombidiformes
SUBORDER: Prostigmata
SUPERFAMILY: Eriophyoidea
FAMILY: Eriophyidae
SUBFAMILY: Phyllocoptinae
GENUS: *Phyllocoptes*

Notes on taxonomy and nomenclature

Rose rosette disease was first reported in the 1940s in California and Wyoming, USA, and Manitoba, Canada (EPPO, 2018). The aetiology of the disease remained completely unknown for many decades afterwards until Gergerich and Kim (1983) discovered virus-like particles in the cells of diseased plants that were morphologically identical to particles of yellow ringspot of redbud. Di *et al.* (1990) subsequently identified four double-stranded RNAs in symptomatic plants. These studies strongly suggested the causal agent was a virus, and a couple of decades later, the virus was characterised by Laney *et al.* (2011) and provisionally named rose rosette virus (RRV). Laney *et al.* (2011) demonstrated a clear correlation between the presence of RRV and the disease, detecting RRV in 84 out of 84 symptomatic plants and in none of the 30 asymptomatic plants tested. Using next generation sequencing, Di Bello (2015) then demonstrated that RRV was the only virus present in symptomatic plants, and not part of a complex, therefore confirming RRV as the sole causal agent of the disease. Di Bello (2015) also identified additional RRV segments, bringing the number of RNAs in the virus genome up to seven.

RRV belongs to the genus emaravirus, of the family Fimoviridae (ICTV, 2020). Members of this genus are characterised by their segmented, linear, single-stranded, negative sense RNA genomes (ICTV, 2020). Aside from RRV, the genus includes eight other viruses, namely *Actinidia chlorotic ringspot-associated emaravirus*, *Blackberry leaf mottle associated emaravirus*, *European mountain ash ringspot-associated emaravirus*, *Fig mosaic emaravirus*, *High Plains wheat mosaic emaravirus*, *Pigeonpea sterility mosaic emaravirus 1*, *Pigeonpea sterility mosaic emaravirus 2*, *Pistacia emaravirus B*, *Raspberry leaf blotch emaravirus*, and *Redbud yellow ringspot-associated emaravirus*.

Biology and ecology

RRV

Lifecycle

The lifecycle of the virus is initiated when a viruliferous mite feeds on, or an infected scion is grafted onto, a non-infected host plant (Di Bello, 2015). The virus subsequently multiplies and moves systemically through the newly infected host (Diakaki *et al.*, 2019). Movement of the virus from an infected scion to the rootstock can occur within 1-2 weeks, to the lower nodes within 2 weeks, and into the roots within 3 weeks (Doudrick, 1984, as cited by EPPO, 2018). Although RRV is able to move to all parts of the plant, the viral concentration is not always the same in each part, and some parts can remain asymptomatic (Diakaki *et al.*, 2019; Stevens *et al.*, 2020).

Phyllocoptes fructiphilus

Lifecycle

Phyllocoptes fructiphilus has two different forms: deutogyne, which is a form that appears later in the year to survive winter and does not reproduce in the same year as its genesis; and protogyne, which is a form seen in the spring and summer and which reproduces in the same year. Deutogyne females of the mite overwinter in protected places on the host, such as under bud scales, underneath the bark or in clumps of overwintering foliage (Figure 2; Amrine, 2002; EPPO, 2018). In spring, the females emerge and move to developing shoots to lay their eggs, usually one egg per day over their 30 day lifespan (Amrine, 2002; EPPO, 2018). One of their preferred oviposition sites is between the stem and the basal petiole of young leaves (Amrine, 2002). Larvae hatch from the eggs within 3-4 days, develop into nymphs after a further 2 days, and develop from nymphs into protogyne adults after another 2 days (Stevens *et al.*, 2020).

Reproduction of eriophyoid mites is through arrhenotoky, where unfertilised eggs produce haploid males and fertilised eggs produce diploid females (EPPO, 2018). Females mate by picking up the spermatophore of their male offspring after they develop into adults or that of another male. Mated females are then able to lay both male and female eggs. As females are able to mate with their own offspring, it is possible for an entire colony to be produced from a single female.

Phyllocoptes fructiphilus takes 5-14 days at 23°C to complete its development from egg to adult and is capable of having multiple generations during the season (EPPO, 2018; Kassar and Amrine, 1990, as cited by Diakaki *et al.*, 2019). The mite generally builds up numbers in spring and summer, before peaking in September when tender new shoots are at their most abundant (Figure 2; Amrine *et al.*, 1988, and Amrine, 1996, as cited by Diakaki *et al.*, 2019). During the spring and summer, the mite is often found under bud scales, on petals and growing shoot tips, within leaf folds of new shoots and at the base of petioles (Babu *et al.*, 2015; Hoy, 2013; T. Druciarek personal communication, 2018).

Later in the year, deutogyne females hatch from protogyne eggs, and overwinter as temperatures fall, starting the lifecycle once more (Figure 2; EPPO, 2018). Under protected conditions, where temperatures are high all year round, generations can continue uninterrupted (Stevens *et al.*, 2020).

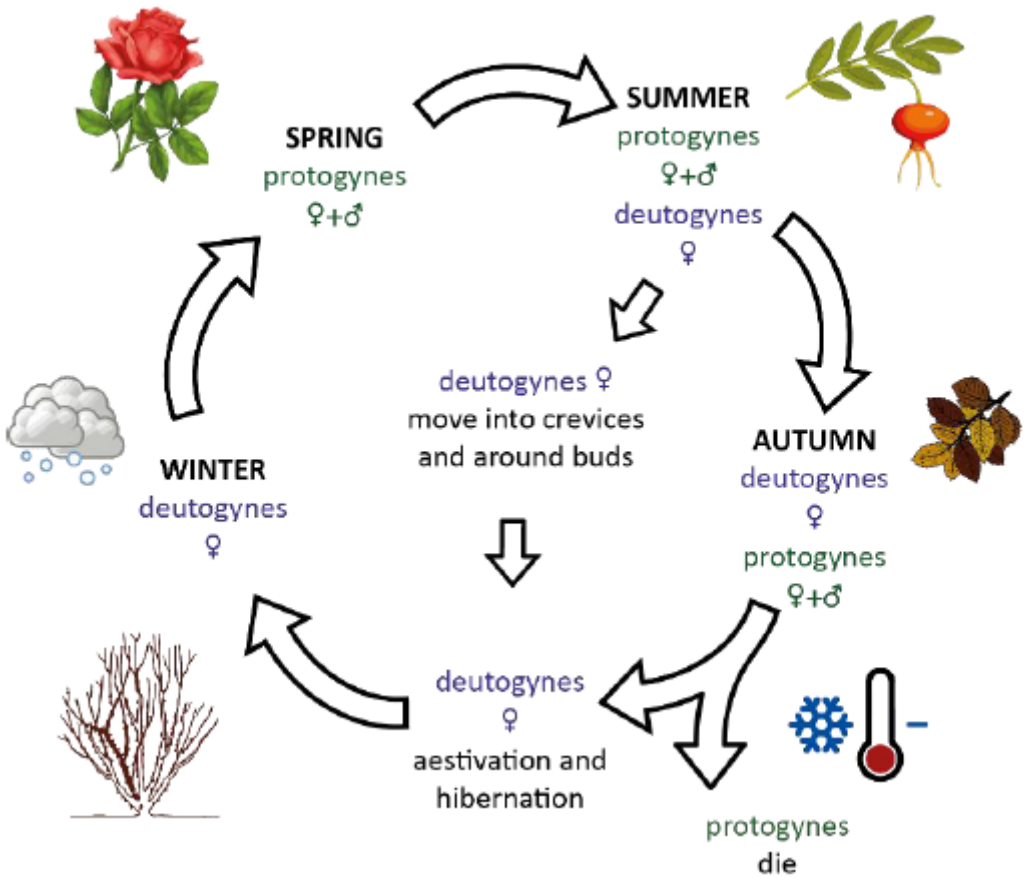

Figure 2. Life cycle of *P. fructiphilus* taken from EPPO (2018).

Habitat requirements

Although the mite needs living green tissue to survive, feeding during the winter is not considered to be necessary (Cloyd, 2013; T. Druciarek personal communication, 2018). When the mite was kept with host material in plastic bags at 4°C in complete darkness, it was able to survive for two months, with the decay of host material being the limiting factor for survival (EPPO, 2018).

Low relative humidity has been linked to lower population numbers (Missouri Botanical Garden, no date).

Hosts/crops affected

RRV

All *Rosa* spp. and cultivars are considered to be susceptible to RRV (EPPO, 2018), and several *Rosa* spp. have already been reported to be infected by the virus. A full and up to date list of susceptible hosts can be found on the EPPO Global database - https://gd.eppo.int/taxon/RRV000/hosts.

Rosa multiflora (multiflora rose) is particularly susceptible, so much so that RRV was initially considered as a biological control agent for the plant (Stevens *et al.*, 2020). While other *Rosa* spp. and cultivars have been observed to be less susceptible and even asymptomatic in some cases, resistance to the virus has not yet been confirmed in the genus *Rosa* (EPPO, 2018).

No species outside of the genus *Rosa* have been reported as hosts of RRV under natural conditions, despite being actively investigated (EPPO, 2018). A survey of 34 plant species nearby to symptomatic roses across several states by Laney (2010), as cited by Laney *et al.* (2011), and field observations by Epstein and Hill (1999), identified no alternative hosts. However, it should be noted that genera other than *Rosa* have been artificially inoculated (Pang *et al.*, 2019).

Rosa spp. native to the UK include *R. rubiginosa* (sweet briar) and *R. canina* (dog rose), which are grown as hedging plants, *R. agrestis* (small-leaved sweet briar), *R. arvensis* (field rose), *R. caesia* (northern dog-rose), *R. mollis* (soft downy-rose), *R. micrantha* (small-flowered sweet briar), *R. pimpinellifolia* (Burnet rose), *R. obtusifolia* (round-leaved dog-rose), *R. sherardii* (Sherard's downy-rose), *R. stylosa* (short-styled field rose) and *R. tomentosa* (harsh downy rose) (Tuffen *et al.*, 2016).

Phyllocoptes fructiphilus

The vast majority of eriophyoid mites are highly host specific. In a study of 3,874 eriophyoid species, Skoracka *et al.* (2010) found that 80% were restricted to one host, 95% were restricted to one genus, and 99% were restricted to one family. *Phyllocoptes fructiphilus* is similarly host specific and has only been reported on *Rosa* spp. (Amrine, 2002). An up to date host list can again be found on the EPPO global database - https://gd.eppo.int/taxon/PHYCFR/hosts..

According to Dr George Philley, the mite prefers roses in which the petiole forms a tight crevice at the stem, such as in *Rosa multiflora*, and less prefers roses which are more open jointed, such as hybrid teas (Roebuck, 2001). As with the virus, though, all *Rosa* spp. are considered to be susceptible to the mite (EPPO, 2018).

Symptoms/signs

Whole plant

Symptoms of RRV are highly variable and depend on the species and cultivar of rose, the age and growth stage of the plant, the climate, and the stage of disease progression (EPPO, 2018). Symptoms initially appear on the leaves, before being seen on the stems and branches, and then on the flowers (Stevens *et al.*, 2020). Disease progression of RRV is described in detail in Anthony (2013) and Tuffen (2016).

Infected roses often die within 1 – 5 years of symptom appearance, usually as a result of increased susceptibility to frost (Babu *et al.*, 2015; Baker *et al.*, 2014; Di Bello, 2015; Hong *et al.*, 2012, Windham *et al.*, 2014). They may also be more susceptible to fungal diseases, such as powdery mildew (Cloyd, 2013). Rose rosette disease progression is usually faster in younger, smaller plants with infected seedlings often dying within a year, single-crowned plants dying within 2-3 years, and parts of multi-crowned plants surviving up to 5 years (Anthony, 2013).

There are some reports of rose recovery in the literature (Amrine, 1996, and Epstein and Hill, 1995, as cited by EPPO, 2018; Illinois, 1999). However, EPPO (2018) suggests this is because the death or removal of symptomatic parts of the plant give the appearance of recovery, whilst RRV is still present in other parts of the plant. Anthony (2013) provides another explanation that temporary reversion may be the result of some leaves not developing red pigmentation, giving them a 'normal' appearance, when actually the leaves are still symptomatic in texture and shape.

Leaves

Symptoms observed on leaves include:

- **Red colouration** (Figure 3; EPPO, 2018). The colouration on the leaves can be deep red to magenta or a more subtle red-pink colour (Anthony, 2013; Hong *et al.*, 2012). It should be noted that young roses of many cultivars show red pigmentation, but that these fade with age, while in RRV infected roses, the red colouration remains (Babu *et al.*, 2015).
- **Distortion** (Figure 4; Babu *et al.*, 2015). This is shown as enation (outgrowths on the surface of the leaves), strapping (unusually long and thin leaves), and a rough, rugose texture (Anthony, 2013; Di Bello *et al.*, 2017, as cited by EPPO, 2018; Hong *et al.*, 2012; Windham *et al.*, 2014).
- **Leaf mosaic** (Figure 5; Babu *et al.*, 2015). This can be yellow and green, with red pigmentation (Anthony, 2013).
- **Abnormal leaf proliferation** (Diakaki *et al.*, 2019).

Stems and branches

Symptoms observed on stems and branches include:

- **Witches' broom** (Babu *et al.*, 2015; Windham *et al.*, 2014). New lateral and vertical shoots show rapid elongation (Baker *et al.*, 2014).
- **Red pigmentation** (Figure 1; Anthony, 2013).
- **Stunting**, as a result of shortened internodes (EPPO, 2018; Ward and Kaiser, 2012).
- **Excessive thorniness** (Figure 7; Roebuck, 2001). Thorns may be pliable i.e. soft and rubbery (Roebuck, 2001).

- **Dieback of shoots and canes blacken and die** (EPPO, 2018; Hong *et al.*, 2012). This may be due to the increased susceptibility to frost and low temperature (Amrine, 2002; Epstein and Hill, 1995, as cited by EPPO, 2018).
- **Distortion** (Figure 8). This is shown as uneven thickening of stems, flattening of stems, spiral growth, and succulent stems (Babu *et al.*, 2015; Epstein and Hill, 1999; Hong *et al.*, 2012; Windham *et al.*, 2014).

Flowers

Symptoms observed on flowers include:

- **Reduced flowering**, as distorted buds fail to open (Baker *et al.*, 2014).
- **Distortion** (Figure 9; Anthony, 2013). This includes fewer petals (EPPO, 2018).
- **Phyllody**, which is the formation of leafy structures in the place of flowers (Baker *et al.*, 2014).
- **Discolouration** e.g. mottling (Hong *et al.*, 2012).

Roots

In the later stages of the disease, plants may produce few rootlets (Anthony, 2013).

Incubation period

Following the grafting of rooted cuttings, rose rosette disease symptoms developed within 41 days to six months (Amrine *et al.*, 1988, as cited by Anthony, 2013), while grafting to large plants gave an incubation period of 60 – 75 days (Anthony, 2013). There are also reports in the literature of an incubation period varying from a few weeks to over a year following grafting (Roebuck, 2001).

When mites were used to transmit the virus, Anthony (2013) reported a variable incubation period of 17 – 160 days in the laboratory to 30 – 279 days in the field. EPPO (2018, citing others, including Amrine *et al.*, 1998) also reported a variable incubation period of 17 – 146 days following mite transmission experiments.

Fig. 3. Red colouration on leaves. Photo by M. A. Hansen, Virginia Tech, School of Plant and Environmental Sciences.

Fig. 4. Leaf distortion. Photo by M. A. Hansen, Virginia Tech, School of Plant and Environmental Sciences.

Fig. 5. Leaf mottling. Courtesy of Patrick Di Bello.

Fig. 6. Witches' broom. Olson et al.

Fig. 7. Excessive thorniness. Olson et al.

Fig. 8. Swollen stem. Photo by M. A. Hansen, Virginia Tech, School of Plant and Environmental Sciences.

Fig. 9. Flower distortion. Photo by M. A. Hansen, Virginia Tech, School of Plant and Environmental Sciences.

Other causes of similar symptoms

Herbicides have been shown to cause similar symptoms to RRV. Glyphosate, the active ingredient of Roundup, can cause witches' broom, while 2, 4-D can cause leaf distortion (EPPO, 2018). Plants are generally able to recover from these injuries within the following year, unless they are repeatedly damaged (EPPO, 2018). Nutrient deficiencies can also cause similar witches' broom symptoms to RRV, but these are usually present across the whole plant, whereas RRV may be quite localised (Hong *et al.*, 2012). Other pathogens could additionally be mistaken for RRV. A newly described phytoplasma can cause witches' broom on *Rosa x damascena*, and a new closterovirus is associated with leaf rosette symptoms in rose (He *et al.*, 2015; Saeed *et al.*, 2016). Wind, temperature, sun, and insect damage can further resemble symptoms of RRV (Ong *et al.*, no date; Sim *et al.*, no date; Singh and Owings, 2018).

Morphology of P. fructiphilus

Most eriophyoid mites including *P. fructiphilus* are spindle shaped, yellow to brown in colour, have four legs (Figure 3; Babu *et al.*, 2015; Roebuck, 2001) and are very small, measuring 0.14 - 0.17 mm in length by approximately 0.04 mm in width (Hoy *et al.*, 2013). As such, they are difficult to detect and positively identify to species. Adult protogynes need to be slide mounted to allow the examination of a suite of characters by a specialist using a research microscope at magnifications of 400X – 1000X (EPPO, 2018). One of the most characteristic features is the pattern or ornamentation on the prodorsal shield of the protogyne, which together with other features is used to differentiate *P. fructiphilus* from the closely related species *Phyllocoptes adalius* and *P. resovius*, which also occur on *Rosa* sp., but are not as yet recorded from the British Isles (Figure 4; EPPO, 2018). Further research is required on whether the prodorsal shield can be used for differentiation of *P. fructiphilus* from other species of eriophyoid mites, particularly those from the British Isles.

Figure 10. Scanning Electron Micrograph (SEM) of an adult Protogyne *P. fructiphilus*. Courtesy of G. Bauchan, J. Hammond and R. Ochoa.

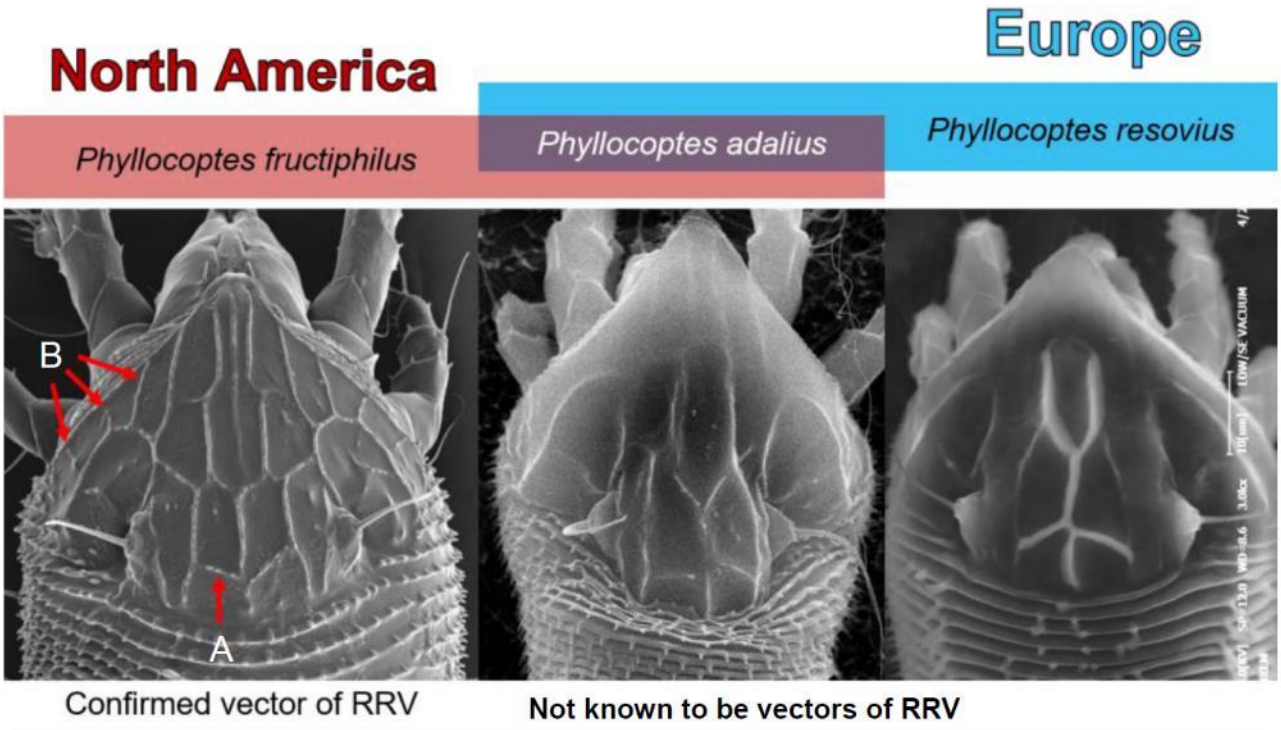

Figure 11. Prodorsal shield differences between *P. fructiphilus* and the mites *P. adalius* and *P. resovius*. (A) short lines which join with the admedian lines are directed towards the anterior end of the shield in *P. fructiphilus*, while in the other two mites, the lines are either perpendicular or directed towards the dorsal end of the shield. (B) three short lateral lines on either side of the prodorsal shield are only found on the shield of *P. fructiphilus* and not on the shield of the other two mites (Druciarek and Lewandowski, 2016, and Druciarek et al., 2016, as cited by EPPO, 2018). The SEM images are courtesy of R. ochoa, T. Druciarek and M. Lewandowski.

Detection and inspection methods

Visual inspection

Rose plants can be visually examined for symptoms of RRV (EPPO, 2018). Symptoms are most evident when the host plant is in active growth and the new tender shoots are most abundant (Amrine *et al.*, 1988, and Amrine, 1996, as cited by Diakaki *et al.*, 2019). In the field, this is likely to be in the spring, while in glasshouses, this may be prior to harvest (Diakaki *et al.*, 2019). Although, there are some symptoms, such as witches' broom and excessive thorniness, which are more obvious in winter when the foliage is not present (Stevens *et al.*, 2020). Because symptoms of the virus are not characteristic during the early stages of infection and can be confused with herbicide damage, environmental factors, and other pathogens, the identity of RRV should be confirmed using molecular testing.

Visual inspection for *P. fructiphilus* is very difficult owing to the small size of the mite and its tendency to coexist with other mites on the same rose plant (Bauchan *et al.*, 2017; Hoy *et al.*, 2013). The mite therefore needs to be examined using a research microscope, either on plant samples or following extraction from the plant by means of washing and sieving (EPPO, 2018; Monfreda *et al.*, 2009).

Trapping

Various methods of trapping eriophyoid mites have been proposed by Monfreda *et al.* (2009), including the use of sticky tape for active movement, and sticky glass slides, greased plates and water pan traps for aerial dispersal. Spore traps and mite collector traps are further options (Roebuck, 2001; Windham *et al.*, no date). Regardless of the method used, trapping eriophyoid mites is not an easy task (Diakaki *et al.*, 2019)

History of introduction and spread

RRV

The virus is regarded as being native to the eastern Rocky Mountains on *Rosa woodsii* (Martin, 2013). It was first reported in Morden, Manitoba, Canada, in 1940, and shortly after in California and Wyoming, USA (Conners, 1941, as cited by Pemberton *et al.*, 2018; EPPO, 2018). Over the next few decades, the virus spread across the Midwest and the south, with reports in Nebraska (1957), Kansas (1976), Missouri (1978), Oklahoma and Arkansas (1982), Illinois and Kentucky (1985), Indiana (1986) and Texas (1990) (Crowe, 1983; and Viehmeyer, 1961, as cited by Amrine, 2002; Hindal *et al.*, 1988, and Philley, 1995, as cited by Pemberton *et al.*, 2018; Ong *et al.*, no date). By 1996, the virus had also spread as far east as Maryland, Ohio, Pennsylvania, Tennessee and West Virginia (Amrine, 2002; Tipping and Sindermann, 2000). And the virus still appears to be spreading, having recently been reported in Florida (2013), Ontario (2014), Louisiana (2015) and Minnesota (2017) (Babu *et al.*, 2014; Bratsch *et al.*, 2017; EPPO, 2018; EPPO Reporting Service, 2017b; Morgan *et al.*, 2015). The virus is expected to spread further

where hosts are available and the climate is suitable for its mite vector (Stevens *et al.*, 2020).

The rapid expansion of the virus has been attributed to the abundance of naturalised *Rosa multiflora* stands across the USA (Pemberton *et al.*, 2018). *Rosa multiflora* was brought to the USA in the 1700s as a garden plant and rootstock, and was heavily planted in the 1930s to the 1960s for erosion control, strip mine reclamation, as a living fence and as a crash barrier on highways (Amrine, 2002; Hong *et al.*, 2012). The species quickly spread due to the millions of seeds it produces per plant and its ability to vegetatively propagate, and is now considered a noxious weed in many US states (Hong *et al.*, 2012).

RRV was found outside of North America in two ornamental gardens in West Bengal, India, in 2017, following a survey of rose diseases (Charkaborty *et al.*, 2017; EPPO Reporting Service, 2017a). The sequences from the Indian isolates were shown to be highly similar to those of the US isolates (A. Katsiani personal communication, 2017, as cited by EPPO, 2018).

Phyllocoptes fructiphilus

Phyllocoptes fructiphilus was first found and described from specimens taken from its native host *Rosa californica* near Clarksburg, California, USA, and has since been found in a number of other US states (EPPO, 2020b; Stevens *et al.*, 2020). Although the recorded distribution of the mite does not fully correspond with the distribution of the virus, the mite is likely to be underreported because eriophyoid mites are difficult to detect and identify (EPPO, 2018; Stevens *et al.*, 2020). *Phyllocoptes fructiphilus* may therefore be more widely distributed, particularly in areas where the virus has been found (Stevens *et al.*, 2020).

Phytosanitary status

RRV and *P. fructiphilus* are also EPPO A1 listed pests, and recommended for regulation by EPPO member countries, and RRV is a quarantine pest in Morocco (EPPO, 2020).

Distribution

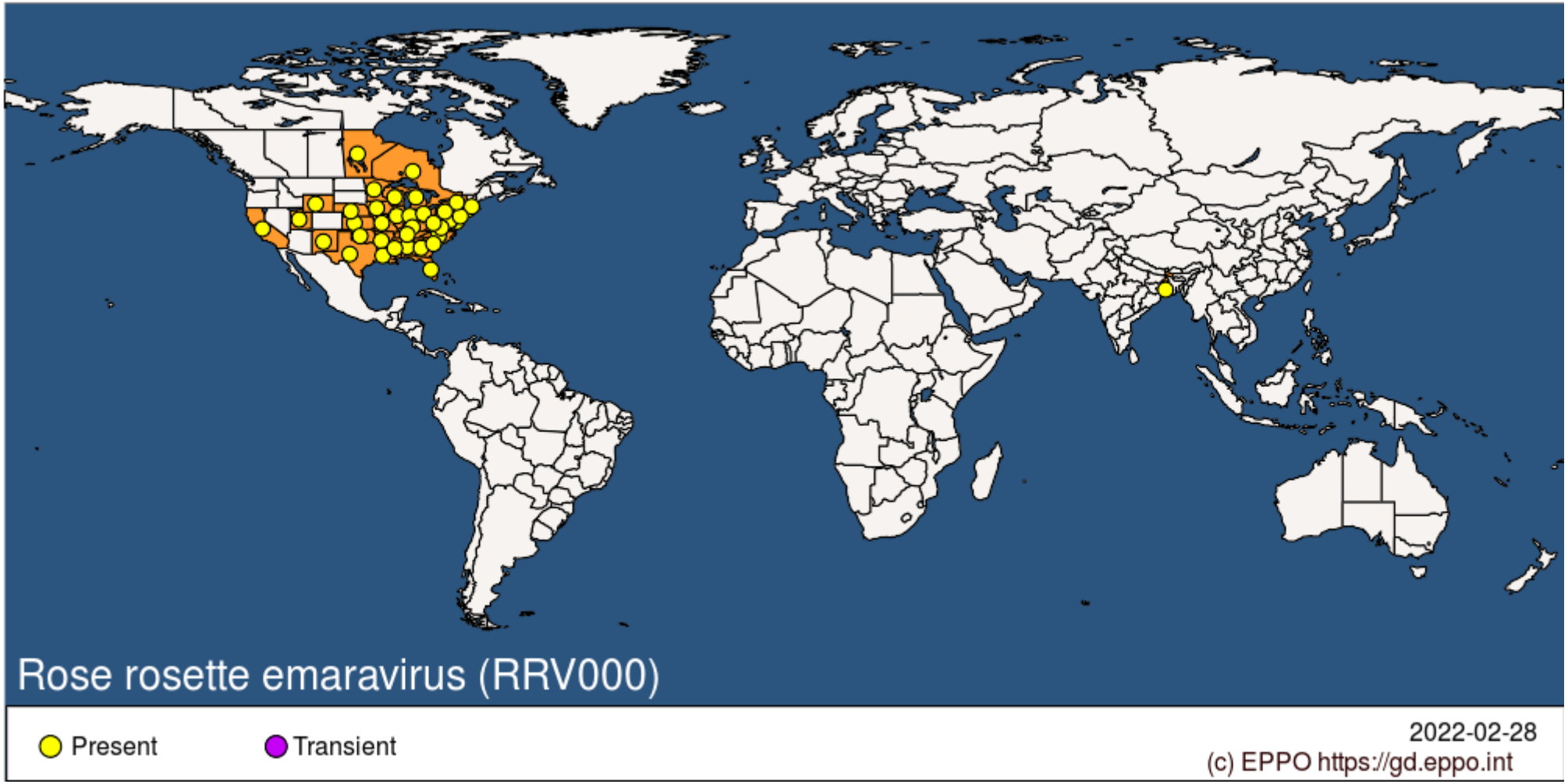

Figure 11. *Rose rosette virus* distribution as of February 2022. (Source: EPPO Global database). The link below provides up to date distribution data.

https://gd.eppo.int/taxon/RRV000/distribution

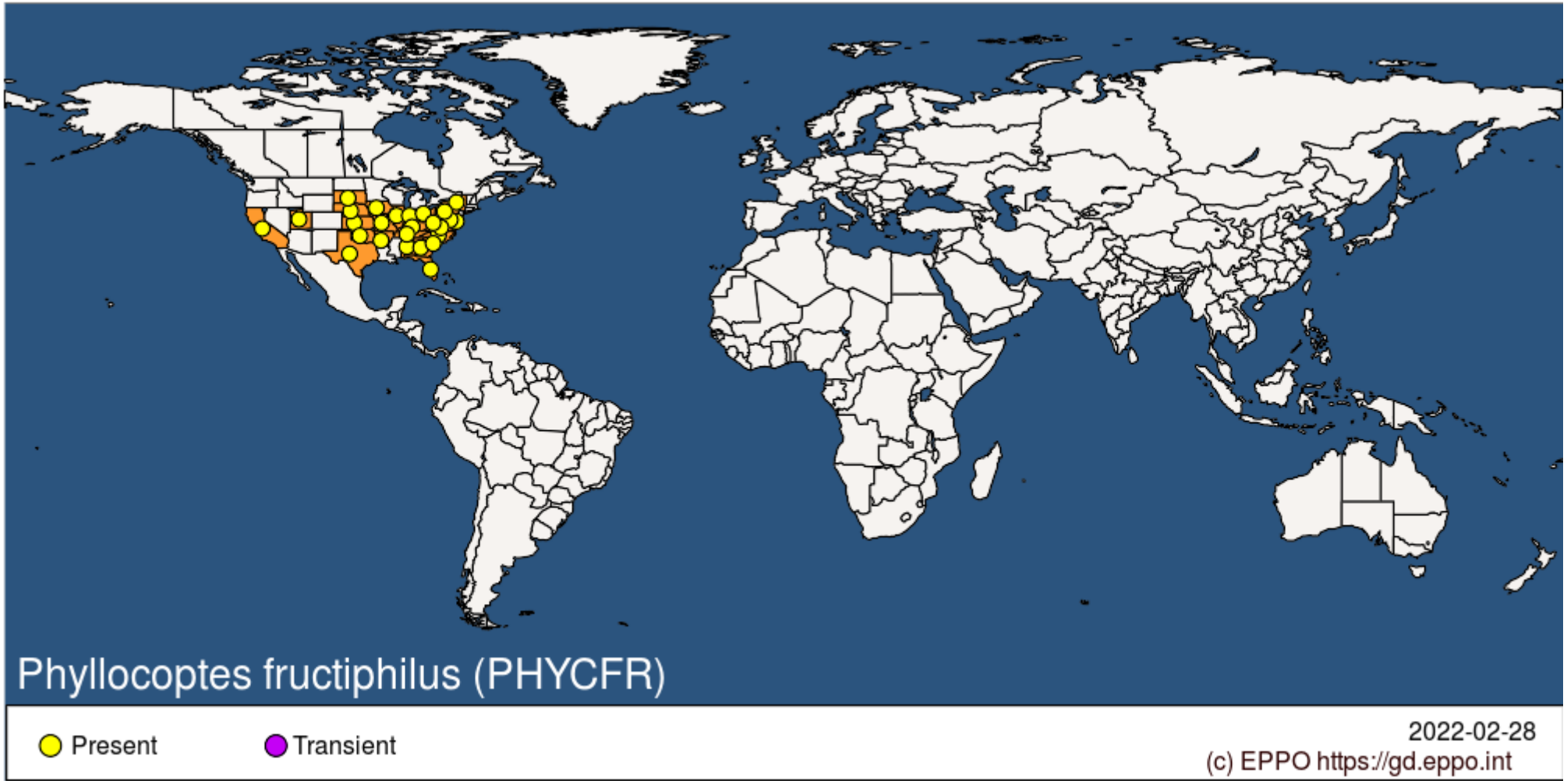

Figure 12. *Phyllocoptes fructiphilus* distribution as of February 2022. (Source: EPPO Global database). The link below provides up to date distribution data.

https://gd.eppo.int/taxon/PHYCFR/distribution

Means of movement and dispersal

Transmission

Vector spread

It has been demonstrated that many emaraviruses are transmitted by eriophyoid mites (Caglayan *et al.*, 2012; Kulkarni *et al.*, 2002; Mielke-Ehret and Muehlbach, 2012). The eriophyoid mite *P. fructiphilus* was first reported as a vector of rose rosette disease by Allington *et al.* (1968), and was subsequently confirmed as a vector of the disease by Amrine *et al.* (1988), as cited by Pemberton *et al.* (2018). More recently, Di Bello *et al.* (2015) showed that the virus itself, and not just the disease, is transmitted by the mite. Di Bello *et al.* (2015) also identified positive strand RNA in *P. fructiphilus*, indicating that RRV replicates inside of the mite, as negative strand RNA viruses only produce positive strand RNA during replication.

Mites were observed to become viruliferous after a five day acquisition access period (feeding on infected 'Julia Child' rose plants) and to then be able to retransmit the virus to healthy plants after an inoculation access period (exposure) of one hour (Di Bello, 2015). The rate of infections of healthy plants increased with the exposure time, rising from 5% of all plants becoming infected after a one hour to 60% after 14 days and 100% after 30 days. In addition it was found that mites were still able to transmit the virus to 20% of plants after being kept at 4°C for 14 days, a temperature at which they are unable to feed (Amrine *et al.*, 1988, as cited by EPPO, 2018).

Transovarial transmission (from adult to egg) has not been fully studied in *P. fructiphilus*, or proven, whereas transstadial transmission (from stage to stage) has been demonstrated (de Lillo *et al.*, 2015, as cited by Diakaki *et al.*, 2019).

No vectors, other than *P. fructiphilus*, have been identified for RRV. Transmission trials using spider mites failed (Allington *et al.*, 1968) and is consistent with other described emaraviruses, which have only been found to have one mite vector (Mielke-Ehret and Mühlbach, 2012). Although *P. adalius* has also not been shown to be capable of transmission, because of the morphological similarity the mite has with *P. fructiphilus* and the symptoms it causes in roses, it has been suggested as a vector of RRV by Druciarek *et al.* (2014).

Grafting

RRV has successfully been transmitted to healthy plants by bud and shield grafts in greenhouse tests and in the field by root grafts (Amrine *et al.*, 1988, as cited by Anthony, 2013; Anthony, 2013; Doudrick *et al.*, 1986).

Vegetative propagation

Although vegetative propagation has not been confirmed as a means of transmission, it has been suggested by Baker *et al.* (2014). Hong *et al.* (2012) also suggest that pieces of infected, root that remain in the soil could regrow and act as a reservoir for RRV.

Other routes of transmission

Mechanical transmission of the disease into *R. multiflora* has been demonstrated with the use of crude extracts (Doudrick, 1984, as cited by EPPO, 2018; Epstein and Hill, 1995, as cited by Epstein and Hill, 1999). However, symptoms were only shown in 5 of 123 inoculated plants. The methods were also not representative of pruning under natural conditions.

RRV has been detected in pollen by Babu *et al.* (2017a), but further research is needed to confirm the finding and its significance.

RRV is not known to be transmitted by seed, soil, or dodder (parasitic plants) (Di *et al.* 1990; Doudrick, 1984, as cited by EPPO, 2018; EPPO, 2018; Epstein and Hill, 1995, as cited by Epstein and Hill, 1999; Epstein and Hill, 1999).

Natural dispersal

As with other eriophyoid mites, *P. fructiphilus* primarily disperses on air currents (EPPO, 2018). This is generally considered to be a passive process, although it is a common observation that eriophyoid mites will on occasion actively facilitate this process by lifting their bodies up in order to be taken by air currents and enter the air column on warm, sunny days (Amrine, 1996, as cited by Tuffen, 2016). There are also reports of active wind dispersal in other eriophyoid mites (e.g. Nault and Styer, 1969).

Rosa spp. plants that are downwind of RRV infected *R. multiflora* are considered to be more at risk of infection (EPPO, 2018). For example, symptoms of RRV were observed on healthy plants within four weeks of being planted downwind of diseased *R. multiflora* (Hong *et al.*, 2012).

The rate of natural spread of the mite is unknown, but it is thought that the mite could disperse long distances in the wind (EPPO, 2018). It has even been suggested that the mite spread from Oklahoma to North Texas with springtime weather fronts (Roebuck, 2001). In a long-term study of the spread of rose rosette disease (and likely the mite) in Clifty Falls State Park in Madison, Indiana, USA, extensive spread was also observed. In May 1987, 30% of surveyed *R. multiflora* plants were symptomatic, by October the same year 56% were symptomatic, by October 1990 93% were symptomatic, and by the end of the study in 1994, 97% of the surveyed plants were either symptomatic or dead (Amrine, 1996, as cited by Tuffen *et al.*,

2016; Amrine, 2002). Other eriophyoid mites are also capable of long distance spread. *Aceria lantanae* was observed to spread about 40 km per year in Swaziland by Mukwevho *et al.* (2017), and *Aceria tosichella* (wheat curl mite), was observed 3.2 km from the nearest wheat field by Pady (1955), as cited by EPPO (2018). In contrast to these observations, Epstein *et al.* (1997) found that no plants more than 100 m from the source of infection became infected with rose rosette disease in several US counties, and when a spore trap was used in Lucas county, no mites were captured 10 m from the source of infection within 6 weeks (June – July).

In the USA, the rapid spread of RRV has been attributed to the abundance of naturalised *R. multiflora* stands (Pemberton *et al.*, 2018). *Rosa multiflora* is not as prevalent in the UK and is unlikely to play as much of a role in the spread of the virus (Tuffen, 2016). Nonetheless, there are a number of widespread native *Rosa* spp. in the UK, such as *R. canina*, which could play a similar role to *R. multiflora* (Tuffen, 2016). The number of generations the mite is able to complete under UK conditions may also have an impact on the rate of spread of RRV (Tuffen, 2016).

Aside from in the wind, eriophyoid mites are able to disperse by walking from plant to plant if the plants are in direct contact (Sabelis and Bruin, 1996, as cited by EPPO, 2018). *Phyllocoptes fructiphilus* may also move by phoresy on other invertebrates, such as bees and aphids, but this has not been demonstrated (EPPO, 2018). Other authors note that while phoresy happens in eriophyoid mites, it is likely to be rare and accidental (Zhao and Amrine, 1997, and Zhao, 2000, as cited by Skoracka *et al.*, 2010). Splash dispersal or by rain has also been reported for eriophyoid mites (Jeppson *et al.*, 1995, and Schliesske, 1977, 1990, as cited by EPPO, 2018), but this is likely to be the least frequent of the different modes of spread (Michalska *et al.*, 2010).

Human assisted spread

Long distance spread

RRV and *P. fructiphilus* can potentially be associated with plants for planting and cut flowers of *Rosa* spp. in trade. These two pathways are regulated under current UK legislation and help reduce the likelihood of entry of RRV and the mite into the UK. Plants of *Rosa* spp., other than seeds and plants in tissue culture, can only be imported from Canada, India, Mexico or the USA if they have been grown throughout their life in an area free from RRV and *P. fructiphilus*, and they have been packed to prevent the infestation of the mite during transport. While, plants of *Rosa* spp. in tissue culture can only be imported from Canada, India, Mexico or the USA if the mother plants have been tested and found free from RRV.

Other pathways of spread, including seed, pollen and rose hips, were not considered viable pathways by EPPO (2018). However, further research is required to discount pollen as a pathway, following the finding of RRV in pollen by Babu *et al.* (2017a).

Local spread

As with the eriophyoid mite, *Calepitrimerus vitis*, which was found on the hands and clothes of grapevine workers (Duffner *et al.*, 2001), *P. fructiphilus* has the potential to be moved on tools, equipment, clothes and other objects.

Control

Resistance

Several species of roses have been reported to have resistance to rose rosette disease, namely *Rosa acicularis*, *R. arkansana*, *R. blanda*, *R. californica*, *R. carolina*, *R. palustris*, *R. pisocarpa*, *R. setigera* and *R. spinosissima* (Amrine, 1996, Amrine *et al.*, 1995, Epstein and Hill 1995, and Thomas and Scott, 1953, as cited by Byrne *et al.*, 2018). However, these reports are mostly based on observations of symptom development following grafting experiments, and it is possible that the roses were harbouring the virus, but not displaying symptoms (EPPO, 2018). In a more recent study, observations of 638 rose species identified 585 (91.4%) species to be symptomatic, 9 to be suspect (1.4%) and 44 to be asymptomatic (7%) (Byrne *et al.*, 2018). Further work is being carried out to confirm resistance via replicated trials in the asymptomatic rose species. Di Bello *et al.* (2016) also identified the cultivar 'Stormy Weather' to be asymptomatic under greenhouse conditions, but recommended that field testing should be carried out to confirm resistance. Until work on these asymptomatic species has been completed, all *Rosa* spp. and cultivars are considered to be susceptible to RRV (EPPO, 2018).

There has also been evidence of resistance to *P. fructiphilus* in *Rosa bracteata* (Amrine, 2002), but EPPO (2018) concluded that this was not sufficient evidence to exclude this species as a host of the mite. *Rosa carolina* is also considered unsuitable by Amrine (2002), but for the same reason as *R. bracteata*, this should not be excluded as a host of the mite until further evidence is presented.

Cultural controls and sanitary methods

There is no cure for RRV, and any rose which is infected with the virus should be removed and destroyed (Tuffen, 2016). The whole plant should be removed, including the roots (Hand, 2014). Herbicides should then be used to ensure that there is no regrowth from any remaining root fragments (EPPO, 2018). Care should also be taken when removing the plant to avoid spreading the mite vector to other roses (Windham *et al.*, 2014). Precautions include bagging the infected plants, not dragging plants through the site and not leaving the infected plants piled near to the site. As there is the possibility that roses adjacent to any sites of infection may also be infected, but are yet to display symptoms of RRV, it has been suggested that these are removed too (Rowlands, 2015).

Other cultural controls and sanitary methods are as follows:

- Sourcing roses from reputable nurseries, and checking plants at the nursery for RRV (Rowlands, 2015; Ward and Kaiser, 2012)
- Planting roses away from *R. multiflora*, and avoiding planting roses on the prevailing downwind side of *R. multiflora*, as well as on hilltops (Hong *et al.*, 2012). *Rosa multiflora* should be removed within 100 m of the planted roses if possible and monitored for regrowth, with any regrowth removed and destroyed (Hong *et al.*, 2012). In the UK, other prevalent native roses may need to be removed, such as those used in hedging (Tuffen, 2016).
- Spacing roses to prevent mites crawling from plant to plant (Hand, 2014)
- Introducing barriers between the roses and the wider environment (EPPO, 2018). Experiments at the University of Tennessee have shown *Miscanthus sinensis* to be an effective barrier, reducing the incidence of the disease in test plots (Windham *et al.*, 2014).
- Installing a mixed planting with plants other than *Rosa* spp. to reduce the spread of the mite (Olson *et al.*, no date)
- Improving the vigour of plants, making them more tolerant to RRV (Olson *et al.*, no date)
- Monitoring roses for signs of infection, including those around previously infected roses, and removing plants quickly once symptoms are seen (Babu *et al.*, 2015; EPPO, 2018)
- Avoiding the use of leaf blowers that may spread the mite (Missouri Botanical Garden, no date)
- Working from healthy areas to infected areas (Olson *et al.*, no date)
- Cleaning tools and equipment regularly to remove any life stages of the mite and changing clothes when visiting new areas (Missouri Botanical Garden, no date). It should be noted that, while it is suspected that mites are able to move on tools and equipment (Duffner *et al.*, 2001; Singh *et al.*, 2018), this has not been demonstrated to date.
- Reducing mite populations by pruning in late winter, removing and destroying fallen foliar material (Babu *et al.*, 2015; Missouri Botanical Garden), but it is unclear if these will reduce the incidence of the disease (EPPO, 2018)
- All of these actions should be considered from a community perspective (Olson *et al.*, no date)

Biological control

There are no commercial biological control agents available for use against the mite (EPPO, 2018). However, predatory mites from the families Phytoseiidae, Tydeidae and Bdellidae have been observed in association with eriophyoid mites on rose, and should be considered when selecting chemicals to control *P. fructiphilus* (EPPO, 2018; Ochoa *et al.*, 2016, as cited by EPPO, 2018).

Chemical control

Phyllocoptes fructiphilus may be difficult to control using pesticides because of its cryptic lifecycle (Hand, 2014; Roebuck, 2001). Even if the pesticides are able to reach the mite, they may not be able to prevent transmission of RRV completely because the mite has a very short inoculation access period of one hour and the mite will be able to transmit the virus before it dies (Di Bello *et al.*, 2018). Nonetheless, acaricides have been recommended by a number of authors (e.g. Baker *et al.*, 2014; Singh *et al.*, 2018). Growers have reported reduced RRV incidence following the use of abamectin, fenpyroximate and spiromesifen in rotation every 5-7 days from bud break through to the end of the season (AmericanHort, 2013, as cited by Tuffen, 2016). Bifenthrin, fenpyroximate, spiromesifen and spirotetramat have also shown promise in an unpublished study, as plants sprayed at 14 day intervals did not develop symptoms of RRV (EPPO, 2018); horticultural oil has potential after late winter pruning (and after leaflets and petals removed) (Roebuck, 2001); and dimethoate is suggested as being effective when sprayed twice early in the season, the second a week after the first, and then sprayed monthly thereafter (Roebuck, 2001). Hong *et al.* (2012) recommends that acaricides are used from April through to September, and possibly increased during hot, dry weather when mites are most active. Pesticides should also be used in rotation, where possible, to avoid the build-up of resistance (Baker *et al.*, 2014). The full list of acaricides mentioned in the literature are shown in table 1. It should be noted that abamectin, horticultural oil and carbaryl used in combination were not effective (Windham *et al.*, 2017).

Table 1. Acaricides mentioned in the literature for use against *P. fructiphilus*.

Acaricide	UK approval on *Rosa* spp. (as of 14/09/2020) – professional use	Reference
Abamectin	Approved on ornamental plant production (permanent protection with full enclosure)	Di Bello *et al.* (2014)
Azadirachtin	Approved on ornamental plant production (permanent protection with full enclosure)	Rowlands (2015)
Bifenthrin	Not approved	Hong *et al.* (2012)
Carbaryl	Not approved	Hong *et al.* (2012)
Deltamethrin	Approved on ornamental plant production (indoor and outdoor)	Di Bello *et al.* (2014)
Dicofol	Not approved	Illinois (1999)
Dienchlor	Not approved	Illinois (1999)
Dimethoate	Not approved	Roebuck (2001)
Endosulfan	Not approved	Babu *et al.* (2015)
Fenbutatin-oxyde	Not approved	Illinois (1999)
Fenpyroximate	Not approved	Windham *et al.* (2017)
Horticultural oil	Specific products would need to be checked	Babu *et al.* (2015)
Imidiacloprid	Not approved	Di Bello *et al.* (2014)
Insecticidal soap	Specific products would need to be checked	Missouri Botanical Garden, no date
Malathion	Not approved	Di Bello *et al.* (2014)
Permethrin	Not approved	Di Bello *et al.* (2014)
Pyrethrin	Approved on ornamental plant production (permanent protection with full enclosure)	Di Bello *et al.* (2014)
Spiromesifen	Not approved	Windham *et al.* (2017)
Spirotetramat	Approved on ornamental plant protection (indoor and outdoor)	Windham *et al.* (2017)
Sulfur	Specific products would need to be checked	Rowlands (2015)

Impacts

RRV reduces the aesthetic appearance of roses, impacts negatively on flower production and quality, and can kill roses within 1-5 years of symptom development (EPPO, 2018).

Economic impact

The virus has caused adverse economic impacts to the rose industry in the USA. Conner and Hagan (2012) reported an impact of the disease on containerised rose production, and one business even reported a 25% reduction in gross revenue because of the virus

(https://www.youtube.com/watch?v=2YUoSOxKnCw&list=PLRyqQJrldHJE0T-4XVZjYUlxfSJNH7fTu&index=5).

Home gardens, commercial landscapes and botanic gardens have also been affected by RRV (Ward and Kaiser, 2012). Fort Worth Botanic Garden in Texas, for example, had to remove all of their roses (Pope, 2019). Cranford Rose Garden also had to replace many roses because of the virus, and an outbreak in Manassas, Virginia, was reported to destroy 20 old rose gardens (Owens, 2011; Shaner, 2006,). In Southland, Texas, the cost of removing and replacing rosebushes in central reservations and in parks amounted to $500,000 (Bahari, 2015). In addition to the costs of losing and replacing roses, there have also been costs relating to reduced popularity and tourism. As a result of RRV infecting two thirds of rose beds in Tulsa Rose Garden, less weddings were being held there and, in 2016, the garden had to cancel a wine and roses evening (Aspinwall, 2014, as cited by Tuffen 2016; Fox 23 News, 2016). Roses used in landscaping were also reported to decrease in popularity (Holloway, 2015).

Although there have been few reports of impacts, the mite is also considered to cause damage to roses at high population densities and be a pest in its own right (EPPO, 2018).

Because of the impact the virus was having in the USA, a $4.6 million research project funded through the USDA's Small Crop Research Initiative was set up to tackle the virus (UDaily, 2014). The project team was made up of researchers, extension personnel and rose breeders, and in the long-term was principally investigating sources of resistance.

Similar impacts to those seen in the USA, such as reduced rose production, rose losses in botanic gardens and landscapes, and diminished popularity in roses, are also expected in the UK (Tuffen, 2016). Additional costs associated with the control of the virus and vector are also likely (EPPO, 2018).

Many roses may be cultivated in the UK. Several thousand rose varieties have been developed over many years from around 150 wild rose species and their hybrids (Scott-Macnab *et al.*, 1997).

Environmental impact

Very few environmental impacts have been observed in the USA, besides the positive impact of the virus on the invasive *R. multiflora* (EPPO, 2018).

Rose species native to the British Isles include *Rosa agrestis* (small-leaved sweet briar), *R. arvensis* (field rose), *R. rubiginosa*, *R. caesia* (northern dog-rose)*, R. canina, R. mollis* (soft downy-rose), *R. micrantha* (small-flowered sweet briar), *R. pimpinellifolia* (Burnet rose), *R. obtusifolia* (round-leaved dog-rose), *R. sherardii* (Sherard's downy-rose), *R. stylosa* (short-styled field rose) and *Rosa tomentosa*

(harsh downy rose) (BRC, 2020; Tuffen, 2016). RRV has the potential to negatively impact ecosystems associated with these species, including native invertebrate species, such as the gall forming wasp *Diplolepsis spinosissimae*, which is entirely dependent on *Rosa* spp. (Plant Parasites of Europe, 2019; Tuffen, 2016).

Social impact

Roses are extremely popular garden plants and are of significant cultural significance in the UK. In England, the red rose is the national flower and appears in heraldic symbology, and in Scotland the white rose *R. spinosissima*, also known as Scots rose, is emblematic of Scotland (National Records of Scotland, 2016).

RRV could reduce the appeal of roses, reduce employment, lower the income for those working in the rose industry, and decrease the availability of culturally important rose products, such as the jam of wild *R. canina* (EPPO, 2018; Tuffen, 2016).

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