Department
for Environment
Food & Rural Affairs

Pest specific plant health response plan:

Outbreaks of *Rhynchophorus ferrugineus*

Figure 1. Adult male *Rhynchophorus ferrugineus* © Iya Mityushev (2019)

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Executive summary

Background	
Regulation	GB Quarantine pest
Key Hosts (2.3*)	Palms
Distribution	Widespread across Asia, the Middle East and Mediterranean region
Key pathways	All life stages are cryptic and may arrive within palms
Industries at risk	Amenity, garden centres, nurseries
Symptoms (2.5)	Wilting, desiccation, dieback of foliage, plant death and collapse
Surveillance	
Demarcated zones (5.27-5.31)	Infested zone ≥ 100 m Buffer zone ≥ 500 m
Surveillance activities (5.41-5.47)	• Following confirmation of an outbreak, visual surveys should be carried out in the buffer zone of all palms with a stem diameter greater than 5 cm • Annual surveys be carried out in subsequent years, following the confirmation of an outbreak, comprising of visual surveys and trapping to look for signs of infestation
Response	
Interceptions (5.1-5.6)	Destruction is via chipping, deep burial or incineration. Tracing exercises are carried out where required and an UKPHINs notification should be made.
Outbreaks (5.39-5.47)	• The movement of hosts, plant products and soil into and out of the infested zone should be restricted • All infested plants where there is a risk of spread must be destroyed except any hosts of particular importance which should be considered on a case by case basis • Traps should be installed, and monitoring of remaining hosts should be carried out regularly to check for signs of infestation • Pruning should be restricted during summer months to reduce the risk of spread
Key control measures	
Biological	Entomopathogenic bacteria and fungi
Chemical	Foliar applications of insecticides
Cultural	Removal of infested hosts, use of traps and avoidance of pruning
Declaration of eradication	
Eradication can be declared if the weevil is not detected during annual surveys for five years after the infested material was destroyed	

* 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 Horizon Scanning team. It describes how the Plant Health Service for England will respond if an infestation of *Rhynchophorus ferrugineus* is detected.

1.2 The plant health authorities in Northern Ireland, Scotland, Wales and the Crown Dependencies have been consulted on this plan and will use it as the basis for the action they will take in the event of *R. ferrugineus* 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 responses 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 *R. ferrugineus* and to make stakeholders aware of the planned actions.

2. Summary of threat

2.1. *Rhynchophorus ferrugineus*, the red palm weevil (RPW), is native to Central, South and South-East Asia but has spread significantly due to the trade of mature host species for commercial cropping and landscaping into previously uninfested areas. The pest is now considered to be present on all continents except for Antarctica. In the Middle East and Mediterranean region, the RPW is a significant pest due to the damage seen and the economic, environmental, cultural and historical importance of the host species.

2.2. The pest was first introduced into Europe in 1996 on infested planting material of *Phoenix canariensis* and has subsequently been found in Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, France, Georgia, Greece, Italy, Malta, Montenegro, Portugal, Russia, Spain and Turkey where RPW is considered to be present or under eradication. Findings in Spain (Canary Islands) and Slovenia have been eradicated and the pest is considered to be absent from these countries. To date there have been three separate

interceptions of this pest in the UK. The first was made in June 2014 when a single live adult was found as a ‘hitch-hiker’ in a box of snake gourds (*Trichosanthes*) arriving from Sri Lanka; the second in October 2016 was of 3 dead adults and 21 dead larvae in a round-leaf fountain palm (*Saribus rotundifolius*), imported from Italy (following eradication measures, the pest was declared eradicated in 2020 (see 2.8) and the third in May 2020 was of a single live adult trapped under the plastic of a pre-packed head of broccoli imported from Spain.

2.3. The RPW feeds primarily on palm trees in the family Aracaeae, and typically on hosts with a diameter greater than 5 cm at their base.

2.4. There is mention of the pest feeding on the non-palm hosts, *Agave americana* (American agave) and *Saccharum officinarum* (sugar cane) but this is questionable. Certainly, the most significant threat comes from their impact on palms. A list of susceptible palm species can be found in Appendix A: Hosts/crops affected and on the EPPO Global database (https://gd.eppo.int/taxon/RHYCFE/hosts).

2.5. The immature stages develop within the host palm, whilst adults may remain within the host but can live outside and fly between suitable hosts to mate and oviposit. Adults are attracted to wounded, damaged or dying palms by aggregation pheromones produced by males in combination with kairomones (chemicals emitted by the host which attract the beetle), such as the resulting fermentation products from the damaged host. Eggs are usually laid at the base of living fronds, and after two to five days, larvae emerge and bore into the hosts crown, feeding on soft succulent tissue using their large chewing mandibles. The larvae can be found anywhere within the palm but often feed on the growing tissue in the crown, and several generations can overlap. Generations of larvae feeding, result in extensive damage and severe infestation.

2.6. Early symptoms are often difficult to detect as entry holes can be covered by offshoots or fibres and the plants may not show signs of deterioration until the infestation is severe. Symptoms often resemble those of drought stress, as feeding tunnels and galleries disrupt the vascular system in the host, with the resulting symptoms including wilting, desiccation and necrosis of the foliage. Other symptoms can include brown sticky oozing from the trunk and ejected frass with a fermented odour, whilst severe infestations can result in the deformation or destruction of new foliage, bending of old leaves which appear umbrella-like, foliar dieback of the crown, rotting of the crown, collapse and host death. This has led to serious economic impacts in areas of commercial

cropping, as well as environmental and social impacts in areas where the hosts are frequently used for landscaping.

2.7. The main pathway for long distance spread is the movement of planting material cryptically infested with life stages of RPW. This is considered to be the reason why the pest has spread so quickly across palm growing areas of the world and has resulted in severe quarantine restrictions being implemented in different countries.

2.8. Three findings of *Rhynchophorus ferrugineus* have been made in the UK, with the most significant being in Essex in October 2016. A round-leaf fountain palm (*Saribus rotundifolius*), imported from Italy, was found containing numerous larvae and a few adult beetles. The plant was destroyed by incineration, and follow up surveys of susceptible palms within 10 km of the affected trees were carried out, along with tracing of potentially infested material to other areas of risk. No further finds were made, and the pest was declared eradicated in 2020.

3. Risk assessments

3.1 *Rhynchophorus ferrugineus* has an unmitigated and mitigated UK Plant Health Risk Register score of 32. 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://secure.fera.defra.gov.uk/phiw/riskRegister/viewPestRisks.cfm?cslref=18191).

3.2 Pest risk analyses (PRA) have been carried out by China (Ju & Aziz, 2011), EPPO (2003) and Ghana (CABI, 2021). The EPPO PRA concluded that RPW was likely to establish in the Mediterranean region and will have a medium-high impact on ornamental and date palm production, partly due to the difficulties in eradication.

4. Actions to prevent outbreaks

4.1 *Rhynchophorus ferrugineus* is a GB Quarantine Pest (Schedule 1 of The Plant Health (Phytosanitary Conditions) (Amendment) (EU Exit) Regulations 2020) and is therefore 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.

4.2 *Rhynchophorus ferrugineus* is listed in Annex IIA of Commission Implementing Regulation (EU) 2019/2072. Annex IIA is the list of Union Quarantine Pests which are absent from the Union territory, and as such they are prohibited from being introduced into, moved within or held, multiplied or released into the Union territory.

4.3 *Rhynchophorus ferrugineus* is an EPPO A2 listed pest. These are pests that are locally present in the EPPO region and recommended for regulation by EPPO member countries.

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

5. Response

Official action to be taken following the confirmation of *Rhynchophorus ferrugineus* on imported plants and produce

5.1. If RPW 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. Samples should be sent to Fera Science Ltd., Plant Clinic, York Biotech Campus, Sand Hutton, York, YO41 1LZ (01904 462000), in a sealed rigid container, which is not liable to be crushed, within at least two further layers of containment. Damaged eggs, larvae or pupae should be submitted in tubes of 70% ethanol to prevent further degradation if possible. In instances where either live adults or larvae are suspected, the inspector shall determine the level of plant health risk. The risk will partly depend on the weather conditions, the time of year and the likelihood of the pest escaping and order the appropriate remedial action. This may involve, if possible, the reloading of material back into the freight container and closing the doors or requiring the consignment to be covered to reduce the risk of insect escape.

5.2. When an infestation of RPW 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 destroyed by either wood chipping, incineration or deep burial.

5.3. Where there is a high risk of escape before destruction or foliar insecticides may be used under guidance from the Defra Risk and Horizon Scanning team.

5.4. A UKPHINS (UK Plant Health Interception Notification System) notification should be made upon confirmation of an interception of live RPW. UKPHINS is the IT system for recording findings and non-compliance in order to maintain records and notify other National Plant Protection Organisations (NPPO) of plant health issues.

5.5. If all or part of a consignment has been distributed to other premises prior to diagnosis, trace forward and trace back inspections should take place upon suspicion or confirmation of RPW where possible. Details of recent past and future consignments from the same grower/supplier should also be obtained.

5.6. A pest factsheet to raise awareness of RPW and its symptoms should be made available to importers, garden centres and nurseries where RPW has been found, and to those in the local area and those associated with the infested premises as deemed necessary. A pest alert is available on the Plant Health Portal - https://planthealthportal.defra.gov.uk/assets/factsheets/Rhynchophorus-ferrugineus-Defra-PP-Factsheet-Oct-2016-FINAL4.pdf.

Official action to be taken following the suspicion of a *Rhynchophorus ferrugineus* outbreak

5.8. Suspect 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. Where appropriate, the OTG should also decide who will be the control authority, and the control authority will then nominate an Incident Controller. 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 plan. See the Defra *Generic Contingency Plan for Plant Health in England* for full details.

5.9. 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 1 of the *Defra Generic Contingency Plan for Plant Health in England*). Under most situations, an outbreak of RPW suspected in a planted palm tree is likely to be given a black alert status. A black status refers to a significant plant/pest disease with potential for limited geographical spread.

Restrictions on movements of material

5.10. If RPW is suspected at a nursery or garden centre, all hosts plants and suspect material should be placed on hold pending further investigation.

5.11. If RPW is suspected in the wider environment, such as in an urban landscaping or recreational park, if there is deemed to be a significant risk of spread, certain precautionary measures may be required, such as preventing the movement of hosts within at least 100 m radius of the infested plants, pending further investigation.

Preliminary trace forward / trace backward

5.12. If a palm, group of palms or infested consignment is or are considered as being the source of the suspect outbreak, investigations regarding the origins of infested material should be undertaken where possible. The aim will be to locate other related and therefore potentially infested consignments or hosts moving to and from the site. For findings in the wider environment or older plantings where no trace forward or backward can be done, the most likely source should be identified if possible and investigated.

General biosecurity advice and advisory measures for growers

5.13. Traps should be installed to monitor for the presence of RPW. See point 5.21 for details.

5.14. A summary of other potential control measures is provided in Appendix A.

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 RPW, in accordance with ISPM 6: guidelines for surveillance (https://www.ippc.int/en/publications/615):

- The origin of the palms.
- Details of other premises or destinations where the palms have been sent, where the beetle 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 palms, especially any commercial or non-commercial hosts in parks or gardens.
- Details of the palm species, variety, growth stage, dimensions (diameter or girth at base, approximate height), age/maturity and general condition.
- Description of the surrounding habitat, including all hosts (species and approximate size).
- Area and level of infestation, including life stages and a description of symptoms (photos would be helpful). Symptoms would include crown and foliage dieback, umbrella shaped foliage, a fermented odour and larval tunnelling within the host.
- The location of any known populations, including grid references.
- The date and time the sample was taken, 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.

5.17. Further to information gathering, samples of other RPW infested material should be taken to confirm the extent of the infestation e.g. in surrounding gardens and parks. 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. Any eggs, larvae, pupae or adults found during the course of inspection, survey or host removal operations, should be submitted by the PHSI to Fera Science Ltd. as in 5.1.

5.20. If a palm is suspected of containing RPW, destructive sampling will be required for confirmation, including cutting into the trunk to reveal galleries within the heart of the palm. This may require the use of contractors.

5.21. Traps based on a mixture of kairomone and pheromone lures have proven to be successful in several studies. These are commercially available from and some suggestions for successful trapping are provided below:

- Traps should be placed 5 m away from palm trees and somewhere where they are unlikely to be disturbed (by members of the public etc.);
- The black cover should be flush to the floor and the white bucket should be slightly elevated to form a seal and prevent adult escape;
- 6 traps/ha should be used for monitoring purposes;
- 12 traps/ha should be used for mass trapping;
- Traps should be monitored monthly for evidence of adults;
- Lures will remain effective for six weeks.

Diagnostic procedures

5.22. A diagnostic standard (PM7/083(1)) for identification of RPW has been produced by EPPO, (https://gd.eppo.int/taxon/RHYCFE/documents). This

contains a key to distinguishing several members of the *Rhynchophorus* genus and detailed descriptions of the morphological features of *R. ferrugineus*.

Criteria for determining an outbreak

5.23. An outbreak should be declared if there is evidence showing that RPW has established a population within host palms other than those that the pest has been moved to England with. Symptoms are not distinctive enough to confirm an outbreak, so surveillance should be carried out until live stages are found or there is satisfactory evidence to conclude the pest is absent. For example:

- RPW being found at the same infested premises on more than one host of the same species from the same batch of palms. In this case, an outbreak should not be declared.
- RPW being found at the same infested premises but on a different batch of palms. In this case, an outbreak of RPW should be declared if the RPW is thought to have spread from one batch to another.
- RPW being found on a mature palm anywhere in England. Due to the cryptic lifestyle of the pest and difficulties in detection, the decision on whether a finding of RPW should be classified as an outbreak or an interception will be made on a case by case basis and should consider the risk of spread from the infested palm.

Official Action to be taken following the confirmation of an outbreak

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

Communication

5.25. 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.

5.26. The Defra pest factsheet to raise awareness of RPW and its symptoms should be made available to nurseries, garden centres, landowners and importers in the locality of where RPW has been found. It should also be distributed to members of the public in the local area if deemed appropriate by the IMT, and to those associated with infested premises. The pest factsheet can be found on the Plant Health Portal https://planthealthportal.defra.gov.uk/assets/factsheets/Rhynchophorus-ferrugineus-Defra-PP-Factsheet-Oct-2016-FINAL4.pdf.

Demarcated zones

5.27. Once an outbreak has been confirmed, a demarcated area should be established around the known infested palms. This will include two zones:

- The **infested zone**, where the presence of RPW has been confirmed, and which includes all plants showing symptoms caused by RPW and, where appropriate, all plants belonging to the same lot at the time of planting. As a minimum, the radius of this zone should extend to 100 m.

- The **buffer zone**, which should initially extend to at least 500 m from the infested zone, with the exact delimitation based on the level of infestation, environmental conditions, the distribution of host plants and evidence of establishment.

5.28. Initial maps of outbreak sites should be produced by officials.

5.29. All palm hosts within the infested and buffer zones should be surveyed for signs of the beetle (see 5.32-5.38).

5.30. The demarcated area should be adjusted in response to further findings. If RPW is found within an area outside the infested zone, this should be designated as infested and the demarcated areas adjusted accordingly.

5.31. The PHSI should contact garden centres, nurseries and other traders of host plants, as well as owners/managers of amenity land such as parks, within the demarcated areas to inform them of the requirements that will apply to them (see Pest Management Procedures). Controls on the movement of specified palms will be implemented either by statutory plant health notices, or by a statutory instrument, or a combination of the two, depending on the nature and scale of the incident. The location of any demarcated areas will be published on '.gov.uk' in order to inform all other stakeholders (including

residents, businesses and landowners) within the demarcated areas of the requirements that will apply to them.

Surveillance

5.32. All plants belonging to the family Arecacae with a stem diameter of 5 cm or more at the base should be surveyed in the infested and buffer zones. In buffer zones, hosts nearest to the infested zone should be surveyed first, with decreasing priority as the distance increases from the infested zone.

5.33. Often, by the time infested palms become symptomatic, the infestation is severe and the chance of saving the host is low. As the beetle is cryptic throughout its life, apart from when searching for new hosts, destructive or invasive sampling may be required to determine whether a host is infested.

5.34. Due to the cryptic nature of the pest, the primary means of surveillance should be pheromone trapping. Traps can be installed and monitored during the likely emergence period (July to September) as in point 5.21.

5.35. Inspection of palms should be of the whole plant. All life stages of the beetle are cryptic, and detection of early stages of infestation is likely to be difficult. Signs to look for include:

- Entry holes, which may be apparent but are likely to be covered by offshoots or trunk fibres. The position of these varies with host and may be found both at the base of the trunk or at the top below the crown;
- Larval feeding damage or distortion of newly emergent fronds;
- Symptoms synonymous with drought stress such as wilting, desiccation and necrotic foliage;
- Brown sticky oozing exudates and ejected frass or woven cocoons with a fermented odour;
- A fermentation smell caused by larval feeding in the stem;
- Evidence of adults following emergence (this is likely to only occur in the hottest period of the year (between July and September); and
- Foliar dieback of the crown, the bending of old leaves to give an umbrella like appearance and rotting of the crown, symptoms that are associated with more severe infestations.

5.36. Surveys should be carried out annually and should continue until no beetle has been detected for at least two years.

5.37. The first surveys of the demarcated area should be carried out as soon as possible after the outbreak has been discovered. Subsequent surveys should be carried out during the summer, as this is likely to be when the beetle is most active.

5.38. To aid surveillance, palms to be inspected or which have been inspected can be mapped using GIS software or similar.

Pest management procedures

5.39. The movement of host plants, plant products and soil out of or within the demarcated zone should be restricted, unless otherwise agreed by the IMT.

5.40. All infested plants (those with associated pests), where there is a risk of spread, should be destroyed as in 5.45-5.47. If there are plants of particular importance in the infested area, the IMT will determine whether they can be excluded from the need for destruction as long as they can be treated using an alternative method (see 5.41).

- The removal of host plants will remain the responsibility of the occupier or other person in charge of the premises.

- In the case of private householders, officials may agree to organise the removal of hosts, with responsibility for payment costs remaining with the occupier or other person in charge, or for it to be undertaken by the local authority which will be responsible for determining whether to accept responsibility for payment of costs 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.

5.41. Infested hosts where specimen palms are of conservation, historical or economic significance may be considered for alternative treatment options to destruction, subject to approval to the IMT. These treatments could include:

- Entomopathogenic nematodes, including *Steinernema carpocapsae*, which have been shown to provide effective control and are used as part of an IPM strategy in Spanish outbreaks. These can be applied via a spray application to the trunk and base of fronds to provide both preventative and curative protection.

- Entomopathogenic bacteria and fungi, such as *Bacillus thurinigensis* and *Beauveria bassiana*, which have been shown to provide effective control against RPW both as preventative and curative methods, although their use in the field is less well studied.

- Preventative or curative chemical treatments. Despite the majority of chemicals used for the control of RPW not being approved for use in the UK, if deemed appropriate by the IMT it may be necessary to apply preventative or curative chemical treatments. Application methods such as crown spraying, crown drenching, bark sprays, trunk injection, soil injection and soil drenches are all noted as potential application methods in the literature. Of these, trunk injection appears to be the usual application method, as it reduces any potential drift, increases the likelihood of contact with the pest and can deliver a suitable treatment without relying on plant uptake to achieve a more rapid effect. In Spanish outbreaks another method has been to permanently install pipelines which reach the top of taller palms with 2-4 mini sprinklers attached to provide treatment of the crown.

    - If the situation demands it, it may be necessary to require the use of pesticides even in organic crops or those where biological control agents are being used.

    - Growers should be placed under notice to apply the recommended pesticides and make the applications using their own or contractors equipment. Records of applications will be kept, including details of the amount of product and water use. All pesticide applications will be made in accordance with pesticide approvals and 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.

    - Before the use of insecticides in the wider environment, any particular risks relating to each site (e.g. proximity to water bodies or footpaths) will be considered. Applications will not be made if the risks are considered unacceptable.

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

5.42. Remaining hosts in the infested and buffer zones should be monitored for palm deterioration and other signs of RPW.

5.43. Traps should be installed as described in 5.21 if not already in place.

5.44. Palms should not be pruned in the summer in the infested and buffer zones as this releases plant volatiles that may attract adults and cause spread to new areas. Any pruning scars should be treated with an insecticide to prevent the entry of female weevils.

Disposal plan

5.45. During the summer RPW infested palms should be destroyed/processed as soon as possible after they have been felled to reduce the risk of spread. Options for destruction/processing are:

- Chipping to dimensions of not more than 25 mm in thickness and width. This would be the most appropriate method of disinfesting smaller hosts.
- Burning or incineration. Burning either in situ (under an Environment Agency exemption, which allows a total quantity not exceeding 10 tonnes to be burned in any period of 24 hours) or at a commercial incinerator.
- Deep burial of non-hazardous waste at a local authority approved landfill site.
- Other methods of disposal, such as biomass, may be considered on a case by case basis.

5.46. In cases where a local authority has the necessary equipment and facilities to carry out the removal and destruction of host material in amenity areas, arrangements may be explored with the authority concerned for the disposal of material from other sources such as private dwellings and commercial premises.

5.47. Any disposal of waste material must be done in accordance with the relevant legislation. Growers need to obtain permission for exemptions from the Agricultural Waste Regulations from the Environment Agency. No charges are made for these exemptions. Further information on activities that require a permit and those which require the registration of an exemption can be found on the EA website at: https://www.gov.uk/topic/environmental-management/environmental-permits.

6. Criteria for declaring eradication/change of policy

6.1 Due to the projected life cycle of RPW in the UK, the minimum time period before RPW can be declared eradicated (by the Chief Plant Health Officer) will be if no RPW is found for five years following the removal of the infested material.

7. Evaluation and review of the contingency plan

7.1 This pest specific contingency plan should be reviewed regularly to consider any changes in legislation, control procedures, pesticides, sampling and diagnostic methods, and any other relevant amendments.

7.2 Lessons should be identified during and after any outbreak of RPW or 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 *Rhynchophorus ferrugineus*

Identity (EPPO, 2020; CABI, 2019; Defra, 2021)

PREFERRED SCIENTIFIC NAME	AUTHOR (taxonomic authority)
Rhynchophorus ferrugineus	(Olivier, 1790)

CLASS: Insecta

ORDER: Coleoptera

FAMILY: Dryophthoridae

COMMON NAMES:

Red palm weevil

Asiatic palm weevil

Coconut weevil

Palm weevil

Red stripe weevil

SYNONYMS:

Curculio ferrugineus Olivier, 1790

Cordyle sexmaculatus Thunberg, 1797

Calandra ferruginea Fabricius, 1801

Rhynchophorus pascha v. papuanus Kirsch, 1877

Rhynchophorus indostanus Chevrolat, 1882

Rhynchophorus signaticollis Chevrolat, 1882

Notes on taxonomy and nomenclature

Both larvae and adults in the Dryopthoridae family strictly feed on monocots with *R. ferrugineus* (red palm weevil; RPW) limited to the Araceae. The family Dryopthoridae is noted to be the most damaging to palms worldwide with species in the genera *Rhynchophorus* and *Dynamis* being referred to as palm weevils (Giblin-Davis *et al.*, 2013 and Rochat *et al.*, 2017). The *Rhynchophorus* genus is composed of 10 species, seven of which attack palms, including RPW (CABI, 2020).

There has been taxonomic confusion surrounding *R. ferrugineus* due to the large phenotypic variability of the weevil. The body colour can range from entirely orange to entirely black with those in between showing variation in the number and size of their black markings (Giblin-Davis *et al.*, 2013). Due to this, several different species were described, later being synonymised to *R*. *vulneratus* (Rochat *et al*; 2017). Studies by Hallet *et al.* (2011) found these two species to be very similar and suggested that *R. ferrugineus* and *R. vulneratus* should be considered colour morphs of the same species and synonymised under the name *Rhynchophorus ferrugineus*.

Molecular studies by Rugman-Jones *et al.* (2013) disputes this as after comparing DNA sequences from native and invasive populations of *R. ferrugineus* the data showed evidence of at least two allopatric species. In this study *R. ferrugineus* is concluded to be native only to northern and western parts of continental southeast Asia, Sri Lanka and the Philippines and is responsible for nearly all the invasive populations worldwide, whilst another species, now resurrected under *R. vulneratus*, was predominantly found with a more southern distribution in Indonesia, and likely to only be responsible for one invasive population in the USA. Although both cause similar damage to palms it is concluded that *R. vulneratus* is distinct from *R. ferrugineus*.

Biology and ecology

Life Cycle

The immature stages develop within the host palm, whilst adults may remain within the host but can live outside and fly between suitable hosts to mate and oviposit, with the majority of the life cycle of RPW is spent within the host palm. Adults are attracted to wounded, damaged or dying palms by aggregation pheromones produced by males in combination with kairomones, chemicals emitted by the host which attract the beetle, such as the resulting fermentation products from the damaged host. As the majority of the life cycle occurs within the host, it allows for several generations to overlap, resulting in extensive damage and severe

infestations (El-Mergawy and Ajlan, 2011; Giblin-Davis *et al.*, 2013 and Defra, 2017). EPPO (2020) suggests that it takes 2-3 generations before a host will be killed by an infestation, and in the Mediterranean basin this will require a minimum of two years. Li *et al.* (2010) calculated RPW to require 1,590.72 day degrees above a baseline threshold temperature of 17.41°C to complete one generation, meaning that completing a generation outside in the UK is very unlikely.

Following mating, females use their mandibles to chew a hole into suitable tissue before depositing 2-3 mm long creamy white or yellow eggs into separate holes or cavities in close proximity to each other (Giblin-Davis *et al.*, 2013; Defra, 2017 and CABI, 2020). This is usually done at the base of living fronds (Rochat *et al*; 2017). In the pest's current distribution, the females are also reported laying eggs into wounds created by Rhinoceros beetles (Dynastinae) (Hussain *et al.*, 2013). Whilst there is a beetle called the Rhinoceros beetle in the UK (*Sinodendron cylindricum*), this belongs to a different family (Lucanidae) in the Scarabaeoidea, which has a preference for *Fagus* spp. (UK beetles, 2021). Despite this, it may be possible that female RPW could lay eggs in wounds caused mechanical damage.

Estimates of numbers of eggs laid vary, but most reports are between 200 and 500 eggs per female (Giblin-Davis *et al.*, 2013; Defra, 2017; CABI, 2020 and Vassiliou and Kitsis, 2021). This large quantity of eggs, combined with the ability of females to lay eggs continuously throughout the year, result in a high multiplication rate. Single females are reportedly capable of producing more than five million weevils in four generations over a 14 month period (El-Mergawy and Ajlan, 2011 and Vassiliou and Kitsis, 2021).

Eggs take approximately two to five days to hatch, with a lower temperature threshold of 13.1°C (Dembilio & Jacas, 2011; Giblin-Davies *et al.*, 2013). Eggs hatch into small, legless first instar larvae which bore from the leaf axils into the host's crown, feeding on soft succulent tissue using their large chewing mandibles (Giblin-Davis *et al.*, 2013; Defra, 2017 and Vassiliou and Kitis, 2021). In more mature palms this preferential feeding on soft tissue will mean that larvae are likely to be found closer to the growing point (CABI, 2020).

The larval period can range from 36-78 days and Dembilio & Jacas (2011) have estimated that a thermal constant of 666.5 day degrees (DD) are necessary for larval development. When they are about to pupate, they construct a tough oval shaped cocoon of fibrous strands, which is around 40 mm in length (Defra, 2017 and CABI, 2020). This is constructed from the fibres extracted from tunnelling galleries, with cocoons being found inside the palm, at the base of the fronds or at the centre of the base of the palm (Vassiliou and Kitis, 2021). Pupation in these fibrous cocoons lasts around two to three weeks (Defra, 2017 and Vassiliou and Kitis, 2021), with an

estimated thermal constant of 282.5 DD required for the pupal stage (Dembilio & Jacas, 2011). However, adults may remain within the cocoon until abiotic conditions improve (Giblin-Davis *et al.*, 2013).

Hosts/crops affected

The RPW feeds on palm species in the family Arecacea including: *Areca catechu* (betel nut palm), *Arecastrum romanzoffianum* (Queen palm), *Arenga saccharifera* (sugar palm), *A. pinnata* (sugar palm), *Borassus flabellifer* (toddy palm), *Borassus sp.* (palmyra palm), *Brahea armata* (Mexican blue palm), *Butia capitata* (pindo palm), *Calamus merrillii* (rattan), *Caryota cumingii* (fishtail palm), *C. maxima* (giant mountain fishtail palm), *Chamaerops humilis* (dwarf fan palm), *Cocos nucifera* (coconut), *Corypha utan* (Synonyms *C. gebang* and *C. elata*) (gebang palm), *C. umbraculifer* (talipot palm), *Elaeis guineensis* (oil palm), *Howea forsteriana* (Kentia palm), *Jubaea chilensis* (Chilean wine pam), *Livistona australis* (cabbage tree palm), *L. decipiens* (ribbon fan palm), *L. chinensis* (Chinese fan palm), *L. saribus* (serdang palm), *L. subglobosa*, *Metroxylon sagu* (sago palm), *Oneosperma horrida*, *O. tigillarium* (nibong palm), *Phoenix canariensis* (Canary Island date palm), *P. dactylifera* (date palm), *P. sylvestris* (Indian date palm or silver date palm), *P. theophrasti* (Cretan date palm), *Roystona regia* (synonym Oreodoxa regia) (royal palm), *Sabal umbraculifera* (pygmy date palm), *Saribus rotundifolia* (round-leaf fountain palm), *Trachycarpus fortunei* (Chusan palm) and *Washingtonia* spp.

Plant stages affected

Typically hosts with with a trunk diameter greater than 5 cm at their base (EC, 2011; El-Mergawy and Ajlan, 2011; Defra, 2017; CABI, 2020 and Vassiliou and Kitsis, 2021).

Plant parts affected

The larvae can be found anywhere within the palm but often feed on the growing tissue in the crown (EC, 2011; El-Mergawy and Ajlan, 2011; Giblin-Davis *et al.*, 2013 and Defra, 2017).

Symptoms/signs – description

Early symptoms are often difficult to detect as entry holes can be covered by offshoots or fibres and the plants may not show signs of deterioration until the infestation is severe (Berton *et al.*, 2010; Defra, 2017 and CABI, 2020). Entry sites can be found in different locations on different hosts, with sites on *Phoenix dactylifera* typically attacked at the base of the trunk, whilst *P. canariensis* is typically attacked at the top (Berton *et al.*, 2010).

Symptoms often resemble drought stress, as the feeding results in tunnels and galleries which disrupt the vascular system in the host. Resulting symptoms include wilting, desiccation and necrosis of the foliage (EC, 2011 and Defra, 2017). Externally brown sticky oozing may be seen, as well as ejected frass with a fermented odour (EC, 2011 and CABI, 2019). Severe infestations will result in the destruction of new foliage, bending of old leaves which give an umbrella-like appearance, foliar dieback of the crown, rotting of the crown, collapse and host death (EC, 2011; Defra, 2017 and CABI, 2020). Studies conducted in Sicily found that both taller and male plants appeared to be more heavily infested, which may be relevant for targeted surveying (Conti *et al.*, 2008).

Due to the number of larvae produced, feeding can be heard from outside the trunk, with acoustic detection or infrared systems being able to detect the pest's presence (EC, 2011; Defra, 2017 and CABI, 2019).

Morphology

Eggs: Creamy white to whitish-yellow, smooth and shiny. Oblong in shape although slightly narrower at the anterior end. They are around 3 mm long and 1 mm wide (Defra, 2017; EPPO, 2020).	
Larvae: Creamy-white body with a brown hard head capsule up to 50 mm in length and 20 mm in width. The body is legless and composed of 13 segments (Defra, 2017; EPPO, 2020).	 **Figure 2**. Image or RPW adult, white larva and brown pupa © Christina Hoddle, University of California Riverside

Pupae: Mature larvae construct fibrous cocoons (around 40 mm in length) from palm fibres in which they pupate for three to four weeks (Nisson *et al.*, 2021). Larvae undergo metamorphosis with pupae developing wing cases, legs and other appendages (Defra, 2017). Pupae begin a creamy colour becoming brown with a shiny surface which becomes furrowed and reticulated (EPPO, 2021).	 **Figure 3.** Image of RPW cocoon © Chris Malumphy, Fera Science Ltd.
Adults: Adults are large and can be up to 42 mm in length and 16 mm wide (Defra, 2017). They have a long curved rostrum or snout which is characteristic for weevils and combined with the head can be up to a third of the total length of the beetle. The rostrums are sexually dimorphic, with females having longer hairless rostrums which are more curved and slender (EPPO, 2020). Colouration of adults varies with some being predominantly red with black markings on the pronotum (section of the body behind the head), whilst others are black with a red streak on the pronotum (Defra, 2017; Nisson *et al.*, 2021).	 **Figure 4.** Image of RPW adult © Chris Malumphy, Fera Science Ltd.

Similarities to other species/diseases/plant damages

Pest alerts were produced to help differentiate between three *Rhyncophorus* species (*R. cruentatus, R. palmarum* and *R. ferrugineus*) following the introduction of *R. ferrugineus* into Curaçao in 2010 (Giblin-Davies *et al.*, 2013). The author notes that

differentiating between these species is relatively easy and can be done by using dorsal characters of the pronotum. None of these species are present in the UK.

Having said this, the phenotypic colouration of the beetles can vary significantly (Defra, 2017; Nisson *et al.*, 2021). This can be seen in figure 6 which shows a mix of colour morphs of *R. ferrugineus* and *R. vulneratus*.

Figure 6. Montage of specimens of *R. ferrugineus* and *R. vulneratus* and the differentiations in pattern and colour. © Mike Lewis, University of California Riverside (2021).

Detection and inspection methods

Visual inspections looking for signs of palm dieback is the most common detection method due to the dramatic symptoms which can be seen (Defra, 2017; EPPO, 2020). Unfortunately, by the time symptoms can be seen, the infestation is severe and the chances of saving the host is low, so determining methods for early detection of the weevil are desirable (Giblin-Davis *et al.*, 2013). Visual inspections can be beneficial if inspection intervals are regular, as the removal of infested hosts before adults can emerge can break the life cycle (EPPO, 2020).

Light traps are not effective in attracting the pest. However, pheromone and scent based traps are used both in detection and as a means of mass trapping. Giblin-Davis *et al.* (2013) notes that the weevils are attracted to wounded, damaged or dying hosts, suggesting that kairomones released by damaged palms may be utilised in trapping. This has been used historically, with traps in 1970s Sri Lanka

being baited with split fresh coconut petioles, and traps in Kerala, India, being composed of split coconut logs smeared with fresh toddy (fermented sap from the palm). Both were found to reduce the number of palms attacked by weevils (Gibson-Davis *et al.*, 2013; CABI, 2020).

More recently aggregation pheromones have been used for control and detection of the pest (CABI, 2020). The aggregation pheromone ferrugineol (4-methyl-5-nonanol) has been shown to be effective (Giblin-Davis *et al.*, 2013; Gonzalez *et al.*, 2019). Work by El-Shaffie and Faleiro (2017) found it was attractive to newly emerged adults although the attractiveness of the pheromone decreased over time.

Current trapping relies on using a mixture of aggregation pheromones and food baits to trap adults (Koppert, 2021; Nisson *et al.*, 2021). Nisson *et al.* suggest that neither components are effective in isolation but are very effective in combination. This is backed up by the work carried out by El-Shaffie and Faleiro (2017), who found that only 35% of RPWs were attracted to the pheromone in olfactometer assays. Mass-trapping carried out in California used the aggregation pheromone, palm material and insecticide in bucket traps to reduce population densities (Nisson *et al.*, 2021). A combination of pheromone and food lures is the suggested bait to be used in combination with the Picusan trap, commercially available from Koppert (https://www.koppert.com/picusan/), which are used for attracting both females and males.

Gibson-Davis (2013) and Gonzalez *et al.* (2019) suggest that trapping should include the pheromone, kairomone (often ethyl acetate) and a food bait such as dates, which are replaced every 2 – 4 weeks for maximum efficacy. Several studies in the Middle East and North Africa have found that RPW adults caught in food-baited pheromone traps were increased by two to three times following the addition of ethyl acetate (Gibson-Davis, 2013). Other key factors to consider in RPW trapping are trap design, lure efficiency, lure longevity, type and maintenance of food bait, trap density and placement and efficacy and repellence of insecticides (Gibson-Davis, 2013). Much of the guidance on these factors come from experience in areas with warmer climates and therefore may differ from what is best practice in the UK.

Gonzalez *et al.* (2019) note that traps with a lower level of maintenance would be desirable. For instance, traps using food baits and water need to be topped up regularly, as food spoils and water evaporates. The inclusion of insecticides can also lead to the adults being repelled, but if not included, can lead to the trapped adults escaping. One low maintenance trap is Electrap™, which has won innovation awards and the developers claim it can increase the efficiency of trapping by more than 300% whilst reducing management costs by 50% (UAE FIRST, 2021). The trap is now commercially available in the Middle East (Gonzalez *et al.*, 2019). The premise

of the trap is that the sunlight that enters the trap penetrates an internal radiation chamber that is internally covered in mirrors. The pheromone and kairomone added to this chamber evaporate and the insect is attracted to the vibrational radiation emitted from the chamber. However, this has been disproven as a theory and it is more likely that the insects is attracted to olfactory cues as with other traps. Comparison studies using these serviceless traps and modified and unmodified bucket traps found that the yield was lower in Electrap™, but using more of these may have some benefit due to the reduced maintenance of the traps (Gonzalez *et al.*, 2019).

Early detection of RPW would be beneficial, particularly using non-invasive techniques, so that hosts can be treated rather than destroyed. Several novel techniques have been developed in recent years such as the use of acoustics to amplify the noises created by feeding larvae, drone surveys to detect dieback over a large area, remote sensors such as thermal or infra-red to highlight any changes such as an increased temperature due to fermentation, radars such as the TreeRadarUnit™ (http://www.treeradar.com/TRUSystem.htm) to non-invasively determine the internal structure of hosts and sniffer dogs to detect odours released by the infested trees (Gibson-Davis, 2013; Defra, 2017; Mohammed *et al.*, 2020; EPPO, 2021). Many of these have shown promise in studies but some may need to be developed further before they are of practical use within the field.

Distribution

Rhynchophorus ferrugineus is present in Africa, America, Asia and Europe. The distribution as of September 2021 is shown in figure 7. Full and up to date distribution data can be found at https://gd.eppo.int/taxon/RHYCFE/distribution.

History of introduction and spread

Global spread

The RPW is native to Central, South and South-East Asia (Giblin-Davies *et al.*, 2013; Hussain *et al.*, 2013) but has spread significantly due to the movement of mature plants from infested areas of South and Central Asia to previously uninfested areas such as the Middle East and Mediterranean for commercial cropping and landscape development. When compared to other *Rhynchophorus* spp., Giblin-Davis *et al.* (2013) note that *R. ferrugineus* is the only species which has significantly expanded its range, and it is now present in all continents except Antarctica (Hussain *et al,* 2013).

In its native range (including in Malaysia, Indonesia, Philippines and Sri Lanka) RPW is primarily a pest of coconut (*Cocos nucifera*), and is the host it was detected on in China in the 1990s (Hussain *et al.*, 2013). However, RPW has seen a greater rate of spread since the 1980s as a pest of *P. canariensis* and *P. dactylifera* and is considered a major threat in countries and areas growing these species commercially (Giblin-Davies *et al.*, 2013). For instance, it was reported in the Middle East from date palm plantations in the UAE and Saudi Arabia in the 1980s and has since been found in Iran (1992), Qatar (1996), Israel (1999), Jordan (1999) and Palestine (1999). The pest was first introduced into Europe in Spain (1996) whilst also continuing to spread throughout Asia and is now present widely through Asia, the Middle East and the Mediterranean as well as having some presence in the Caribbean (Hussain *et al.*, 2013; CABI, 2020; EPPO, 2020). All of these findings are likely to have been made 1-2 years after the initial introduction, given the difficulties in detecting the pest early (Giblin-Davies *et al.*, 2013).

Europe

The RPW was accidentally introduced into Europe via infested planting material with the first finding in Spain in 1996 on *P. canariensis* (EPPO Reporting Service, 1996 and EC, 2011). Subsequent findings were made in the following years and the pest is now considered to be present or under eradication in Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, France, Georgia, Greece, Italy, Malta, Montenegro, Portugal, Russia, Spain and Turkey. The pest has been declared eradicated from the Canary Islands, Slovenia and the UK (EPPO, 2021).

UK

To date there have been three separate interceptions of this pest in the UK. The first was made in June 2014 when a single live adult was found as a ‘hitch-hiker’ in a box of snake gourds (*Trichosanthes*) arriving from Sri Lanka; the second in October 2016 was of 3 dead adults and 21 dead larvae in a round-leaf fountain palm (*Saribus rotundifolius*), imported from Italy (following eradication measures, the pest was declared eradicated in 2020. The plant was destroyed by incineration, and follow up surveys of susceptible palms within 10 km of the affected trees were carried out, along with tracing of potentially infested material to other areas of risk. No further finds were made, and the pest was declared eradicated in 2020. A third finding in May 2020 was of a single live adult trapped under the plastic of a pre-packed head of broccoli imported from Spain.

Means of movement and dispersal into the UK

Long distance spread

The main pathway for long distance spread is via the movement of planting material cryptically infested with RPW. This is considered the reason why the pest has spread so quickly across palm growing areas of the world (Giblin-Davies *et al.*, 2013; Dembilio and Jaques, 2015; Faleiro *et al.*, 2019; EPPO, 2021). Infested plant material was also the route of entry into Essex, UK, in 2016, where the beetle was introduced on a palm tree imported from Italy (Defra, 2016).

The import of ornamental palms provides a route for the pest to enter commercial plantations (Giblin-Davies, 2013; Goldshtein *et al.*, 2019). Analysis of georeferenced RPW occurrence data by Goldshtein *et al.* (2019) found that ornamental palms (particularly *P. canariensis*) are preferential hosts for establishment in comparison to date palms. Once established, RPW disperses from these ornamental plantings in urban areas to date palm plantations due to host density and distribution. Giblin-Davies *et al.* (2013) suggests that a high density of preferential hosts in Europe and the Mediterranean exacerbated the rates of geographical spread across the area.

Local spread

The RPW is a strong flyer under the right conditions and, once emerged, adults may disperse up to 900 m to find another host or remain within the host and mate for a further generation. This is dependent on the condition of the host and the external climatic conditions (Giblin-Davis *et al.*, 2013). As it may take 2-3 generations for a host to deteriorate to a point where beetles may leave, RPW adults often remain in the same host. In some areas these generations could occur in a single year (Giblin-Davies *et al.*, 2013), but this is likely to be longer in the UK.

Uninterrupted dispersal distances of more than 1 km have been recorded and marked beetles were found five days after release, up to 7 km away from the point of release (Abbas *et al.*, 2006; EC, 2011; Giblin-Davis *et al.*, 2013). These data come from studies in the UAE, which experiences much higher temperatures than the UK. It is therefore likely that dispersal will be lower in the UK.

As the UK does not have commercial palm plantations, any RPW will likely spread across ornamental plantings in urban areas if introduced. Given that UK palms are likely to be preferential hosts and more dispersed than in areas where impacts are seen, RPW may travel greater distances to find suitable hosts. Conversely, temperatures below 15°C can curtail weevil activity (Massoud *et al.*, 2012), which may result in lower levels of spread being seen in the UK than in other areas.

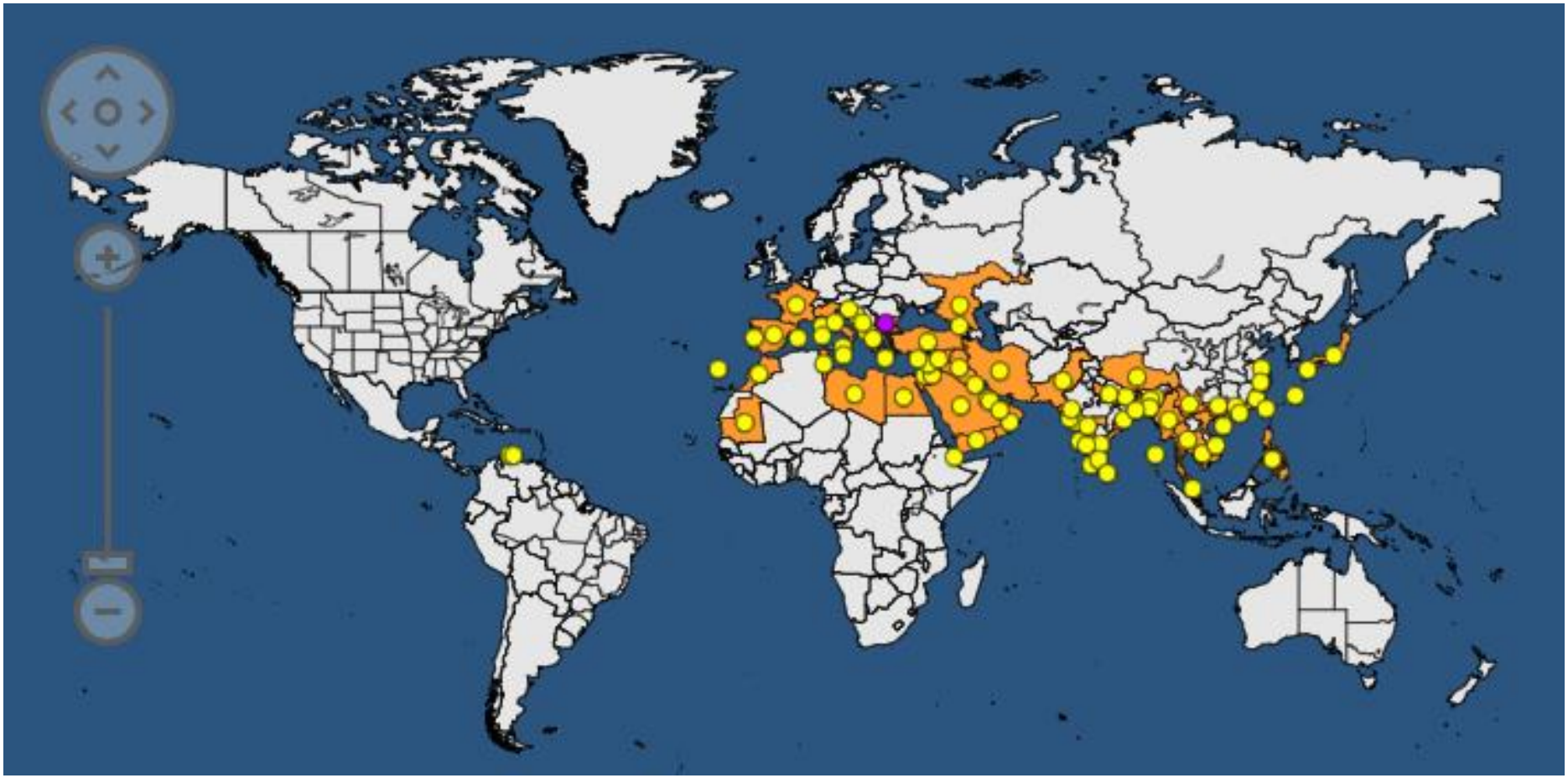

Figure 7. Distribution of *Rhynchophorus ferrugineus* (Source: EPPO, 2021). Up to date distribution data can be found at https://gd.eppo.int/taxon/RHYCFE/distribution.

Phytosanitary status

Table 2. Global categorisations of *Rhynchophorus ferrugineus* (Adapted from EPPO, 2020)

Country/NPPO/RPPO	List	Year of addition
AFRICA		
East Africa	A1 list	2001
Egypt	A2 list	2018
Morocco	Quarantine pest	2018
Southern Africa	A1 list	2001
Tunisia	Quarantine pest	2012
AMERICA		
Brazil	A1 list	2018
Mexico	Quarantine pest	2018
ASIA		
Bahrain	A2 list	2003
Israel	Quarantine pest	2009
Jordan	A2 list	2013
EUROPE		
Georgia	A1 list	2018
Turkey	A1 list	2016
RPPO		
EAEU	A1 list	2018
EPPO	A2 list	2006
EU	RNQP	2019
EU	PZ Quarantine pest	2019
OIRSA	A1 list	1992

Exclusion

Rhynchophorus ferrugineus is a GB quarantine pest (Schedule 1 of The Plant Health (Phytosanitary Conditions)((Amendment) (EU Exit) Regulations 2020) and is therefore prohibited from being introduced into, or spread within GB.

Control

As the beetle is cryptic during all life stages, focusing on one control strategy poses problems, and therefore Integrated Pest Management (IPM) strategies are often recommended for the control of RPW. Such IPM strategies could include several of the management measures below.

Cultural control and sanitary measures

Preventative treatments and the pruning of unwanted offshoots or growing points are mentioned in the literature (CABI, 2020; EPPO, 2021). However, given that most findings are likely to be made once an infestation is causing significant symptoms, the most significant cultural measures are likely to be effective removal and destruction of infested hosts. This could include chipping, burning and burying infested material before any weevils can emerge and infest new hosts (Nisson *et al.*, 2021).

One approach in the future may be the use of host plant resistance. Both antibiosis (where the interaction of the host and pest causes physiological or developmental disorders in the pest) and antixenosis (where the pest is repelled or not attracted to the host), have been identified in palm species in relation to RPW (Dembilio & Jaques, 2015). This resistance has been found in the ornamental species *Chamaerops humilis, Washingtonia filifera* and *Phoenix theophrasti* (Dembilio *et al.*, 2011; Dembilio & Jaques, 2015; Nisson *et al.*, 2021) but, as yet, has not been found in species grown in commercial plantations. Giblin-Davies *et al.* (2013) note that this could be utilised in the management of RPW following further research.

Mass trapping is also an option for reducing population densities (see ‘Detection and inspection methods’).

Biological control

Invertebrate parasitoid and predators

In the literature there are several named parasitoids and predators of RPW, including many species of parasitic mites from India and the Middle East (Dembilio & Jaques, 2015). The Hemipteran bug, *Platymerus laevicollis*, is reported as feeding on RPW,

originally discovered as a fortuitous side effect following its release for the control of another plant pest in Sri Lanka (Dembilio & Jaques, 2015; CABI, 2020).

None of these invertebrate biocontrol agents have proved to be successful when applied on a field scale, and this may be partly due to an incomplete knowledge of the natural enemies of RPW in its native habitat (Murphy & Briscoe, 1999; Giblin-Davies *et al.*, 2013; EPPO, 2021).

Entomopathogenic nematodes

Species of nematode have been identified which provide effective control measures against RPW. The species *Steinernema riobravae, S. carpocapsae* and *Heterorhabditis* sp. were found to be pathogenic to both the larval and adult stages of RPW by Abbas & Hanonik (1999). The authors found that larvae were the most susceptible stage, although propagation of the nematode was greater in the adult stage.

Llácer *et al.* (2009) found *S. carpocapsae* in a chitosan formulation provided good protection both as a preventative (98% effective) and curative (80% effective) application when applied to *P. canariensis* under semi-natural field conditions. *Steinernema carpocapsae* was later shown to provide similar protection on *P. theophrasti* (Dembilio *et al.*, 2011). The nematode was applied by backpack sprayer to the trunk and base of the fronds. Nematodes have been used in Spanish control programmes as part of an IPM approach, and in these outbreaks, it is common practice to permanently install pipelines which reach the top of taller palms with 2-4 mini sprinklers attached to provide treatment of the crown area (Giblin-Davies *et al.*, 2013).

In England *S. carpocapsae* is approved for use without a licence whilst certain species of *Heterohabditis* require a licence for their use. *Steinernema riobravae* is not approved for use in England.

Entomopathogenic bacteria

Isolates of nine different *Bacillus* sp. which were isolated from dead RPW have shown to be effective against eggs and larvae of RPW, indicating some potential for use as a preventative treatment. Of these only *B. licheniformis* was able to give satisfactory control of larvae and would show potential as a curative treatment (Dembilio & Jaques, 2015).

Studies by Pu *et al.* (2017) looked at the widely used *Bacillus thuringiensis* (*Bt*) and its efficacy against RPW. No significant effects were seen in terms of egg mortality,

although hatch times were extended at higher concentrations, which also increased the level of second instar mortality after 15 days (up to 94.32%). Fourth instar larvae were dipped into *Bt* solutions or exposed to treated sugarcane, both of which resulted in significant reductions in boring activity, indicating that *Bt* could also potentially be used in a control strategy.

One study also found the bacterium *Pseudomonas aeruginosa* to be pathogenic in laboratory studies following isolation from naturally infested Indian RPW (Murphy & Briscoe, 1999).

Entomopathogenic fungi

Beauveria bassiana and *Metarhizium anisopliae* are both candidates for use as biocontrols. Strains isolated from infected RPW have been used in trials to evaulate their efficacy (Dembilio & Jaques, 2015). The different strains used have had variable success, both in terms of the life stages affected and the mortality seen. The authors summarise the findings of several studies, with the mortality caused by *B. bassiana* ranging from 12.8% to 85.7% amongst field studies, and another study suggesting it can significantly affect fecundity and egg hatch rates which were

Figure 8. *Rynchophorus ferrugineus* adult killed by an entomopathogenic fungus. © Chris Malumphy, Fera Science Ltd.

reduced to 62.6 and 32.8% respectively. This gives the fungus some potential as a prevetantive treatment.

When *B. bassiana* and *M. anisopliae* were compared, Abdel-Rahman & Abdel-Raheem (2018) found *M. anisopliae* to be more virulent. However, more of the literature seems to focus on *B. bassiana*, which may be because it is commonly used against other pests.

Beauveria bassiana has also been shown to work well in conjunction with insecticides, resulting in 89% pupal and 66% adult mortality when combined with lower concentrations of the insecticide Nitenpyram (Qayyum *et al.*, 2020). This indicates that their use could reduce the cost of management and keep the use of insecticides to a minimum.

One field trial in Spain looked at a novel application method of applying *B. bassiana* as granules to the crown of infested palms. In the study this achieved 70-85% RPW mortality and the formulation was noted as being persistent, therefore allowing it to be applied as a preventative treatment (Güerri-Agulló *et al.*, 2011).

Chemical control

Despite the difficulties associated with chemical control, this remained the main strategy for controlling populations of RPW until the male aggregation pheromone was developed in the 1990s (Al-Dosary *et al.*, 2016). The use of insecticides is difficult due to its cryptic life cycle, and during the evolution of chemical control against RPW several tactics have been tested. These include dressing wounds with repellent agents, filling frond axils with insecticide dusts, foliar spraying, dipping offshoots, drenching of crowns, fumigation, soil applications and trunk injection (Hussain *et al.*, 2013; CABI, 2020). The latter of these appears to be widely adopted in commercial crops but has associated costs due to the equipment and training involved.

In commercial crops both curative and preventative applications are made. Of these Dembilio & Jaques (2015) suggest that preventative measures are more important due to the difficulties in detecting the early stages of infestation. In terms of preventative applications, pruning scars or injuries may be treated with insecticides to prevent the entry of female weevils, and conventional spraying may be carried out in hot spots in order to deter further spread.

Preventative treatments in Valencia, Spain, have consisted of eight treatments per season, using six active ingredients (imidacloprid, thiamethoxam, avermectin, abamectin, chloropyrifos and phosmet), applied in three different ways (crown

sprays, trunk injections and soil drench). One Spanish efficacy trial found that the highest mortality was achieved when sprays and trunk injections of the same insecticide were combined, with the highest efficacy achieved by carbaryl, fipronil and imidacloprid (Hernandez-Marante *et al.*, 2003; CABI, 2020). The efficacy of imidacloprid, in particular, is backed up by various laboratory, semi-field and field trials (Dembilio & Jaques, 2015).

Imidacloprid is no longer approved for use in the UK, but there are products approved for use on ornamental plant production with the active ingredient abamectin. When used in stem injection trials, abamectin had lower distribution within the host than imidacloprid but achieved 50-90% mortality of larvae for up to one month after treatment. Comparatively imidacloprid achieved > 90% for more than two months after treatment (Dembilio *et al.*, 2015).

Curative applications are made via the use of stem or pressure injections. These applications often use insecticides based on carbamates, organophosphates, phenylpyrazoles and neonicotinoids (Dembilio & Jaques, 2015; Al-Dosary *et al*., 2016).

Faleiro *et al.* (2019) note some further issues with current chemical treatments including an overreliance on chemical treatments (possibly due to a lack of natural products), development of insecticide resistant RPW populations, the improper use of insecticides leading to contamination of the environment, insecticidal residues in the food chain and a lack of a standardised protocol for treating infested palms in the early stages of an attack. This may not be an issue for the UK, given the lack of commercial plantations, but it is still worth noting.

Impacts

Economic impact

Severe infestations can result in palm mortality and rotting of the trunk, greatly impacting on yield of palm crops or losses in terms of ornamental plants. European outbreaks in Spain and Italy have resulted in the loss of ornamental palms with high economic values, whilst the impact on date crops in the Middle East has also resulted in high losses to growers (EPPO, 2003). El-Sabea *et al.* (2009) estimate that 1-5% of date plantations in the Arabian Peninsula are infested, equating to $5.18 to $25.92 million in damage costs. Other reports suggest the removal of infested palms in the Middle East and Gulf equates to $8 milllion a year (FAO, 2017).

Indirect economic impacts such as control measures can also be costly, with around $70 million spent in California on susceptible palms (Hussain *et al.*, 2013). In Europe

the FAO has estimated the cost of management (up until 2013) of eradication and replacement of palms in Italy, Spain and France to be €90 million and predicted this cost to rise to €200 million by 2023 (FAO, 2017).

The recent expansion in Europe has also resulted in stricter phytosanitary requirements which may result in additional costs to growers in order to comply with the legislation (Giblin-Davies *et al.*, 2013).

Environmental impact

Due to the large amount of plantings in urban areas and parks in the Mediterranean, the removal of ornamental palms has changed the landscape and resulted in the European Commission introducing emergency measures to try and prevent further spread (Defra, 2017). European palm forests such as the Elche palm forest and Elx date palm grove in Spain or the Theophrastus palm tree forest in Crete are also considered to be at risk, representing large numbers of palms whose losses would impact severely on the landscape (EPPO, 2003; Gilbin-Davies *et al.*, 2013).

Social impact

In the Middle East region, social impacts can be large due to the cultural significance of the date palm in this area. Severe infestations can result in the collapse of large ornamental specimens, which has been seen in Europe and can pose a risk to public health due to their planting in urban areas and parks. Their collapse also reduce the aesthetic beauty of an area (Defra, 2017; CABI, 2020). There may also be implications in terms of losses of palms of historic value, such as potential losses at the Elx date palm grove in Spain which is catalogued as a UNESCO World Heritage Site or the wild forests of *P. canariensis* on the Canary Islands (Giblin-Davies *et al.*, 2013). *Phoenix canariensis* is also noted as being present in 85% of Sicilian historical gardens along with other palm species (Manachini *et al.*, 2013). Outbreaks in these areas could therefore impact on recreation and tourism.

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