Department
for Environment
Food & Rural Affairs

Pest specific plant health response plan:

Outbreaks of *Anoplophora glabripennis*

Figure 1. *Anoplophora glabripennis* adult. © Fera Science Ltd.

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Executive summary

Background	
Regulation	GB Quarantine pest
Key Hosts	*Acer, Aesculus, Corylus, Fagus, Fraxinus, Malus, Platanus, Populus, Prunus, Pyrus, Salix, Sorbus, Ulmus*
Distribution	Canada, China, France, Germany, Italy, Japan, USA
Key pathways	Plants for planting, Wood packaging material
Industries at risk	Amenity, garden centres, nurseries, wider environment
Symptoms (2.2)*	Crown dieback, early senescence, host mortality
Surveillance	
Demarcated zones (5.32-5.37)	Infested zone = 100 m around known infested plants Buffer zone = ≥ 2 km
Surveillance activities (5.38-5.44)	• Visual surveys will be carried out in the infested and buffer zone • Pheromone trapping surveys • Regular surveillance of sentinel trees • Suspicious symptoms found by ground surveys to be followed up by tree climbers
Response measures	
Interceptions (5.1-5.5)	• Consignment should be destroyed or re-exported if dead larvae or feeding damage is seen. • Tracing exercises carried out where required • UKPHINs notification to be made.
Outbreaks (5.45-5.52)	• Infested and symptomatic plants within 100 m of infested plants to be felled and removed • If felling is deemed inappropriate an alternative eradication measure may be feasible • Plants and hedgerows to be cut to ground level • Inspection of felled trees • Sentinel trees to be installed for monitoring • Restrictions on replanting host species
Key control measures	
Biological	N/A
Chemical	Insecticides are unlikely to prevent spread
Cultural	Felling and destruction of infested trees, Trapping
Declaration of eradication	
Eradication can be declared if no pest is detected during annual surveys for six 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 *Anoplophora glabripennis* is discovered.

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 *A. glabripennis* 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 *A. glabripennis* and to make stakeholders aware of the planned actions.

2. Summary of the threat

2.1. *Anoplophora glabripennis* is native to China and Korea, and has become a major tree pest of poplar (*Populus* spp.) in the former (Gao and Li, 2001). The first finding of the beetle outside of Asia occurred in 1996 in Brooklyn, New York, USA (Lingafelter and Hoebeke, 2002). Populations of the beetle have since been discovered elsewhere in the USA, in Illinois, Massachusetts, New Jersey and Ohio, as well as in Ontario, Canada (EPPO, 2017; EPPO reporting service, 2008a, 2013a, 2015a; NAPPO, 2017b). The Canadian outbreak has now been declared eradicated (EPPO reporting service, 2020a). Not long after its discovery in North America, *A. glabripennis* was confirmed in Europe, in Austria in 2001, before being found in France, Germany, Italy, Switzerland, the UK, Russia, Finland, and Montenegro (EPPO reporting service, 2001, 2004a, b, 2009a, b, 2013e, f, 2015b, 2017d, e). A more recent finding of the beetle was made in Lebanon in 2018 (EPPO reporting service, 2018) The beetle is currently under eradication in many of these countries, and has since been declared eradicated from Austria, Finland, Montenegro, Russia, Switzerland and the UK (EPPO reporting service, 2020b, 2020c, 2020d, 2021a, 2021b, 2021c). The beetle has also been eradicated from some outbreaks in France, Germany and Italy where multiple outbreak sites were identified (EPPO reporting service, 2020e, 2021d, 2021e).

2.2. Adult beetles feed on the leaves, bark of twigs, and petioles of these hosts, and females chew pits into the bark where they lay their eggs (largely in the upper trunk and branches), while larvae burrow into the sap and heartwood, forming galleries (Ric *et al.*, 2007). Damage by the larvae can result in crown dieback and early senescence, and eventually the death of the tree (Ric *et al.*, 2007). Feeding damage and the death of trees impacts the economy, with respect to reduced yield and timber quality, the environment, with respect to the loss of ecosystem services, and society, with respect to declining recreational and amenity sites (Gao *et al.*, 1993; Jim and Chen, 2009). Eradication measures used against this pest are also very costly. In the USA, for example, eradication costs as of 2013 were estimated to be US$ 537 million (Eyre and Haack, 2017).

2.3. Eggs, larvae, pupae and adults are mainly associated with the wood material of host trees. When Haack *et al.* (2010) compared 219 interceptions of *A. glabripennis* and *A. chinensis* from 18 countries from 1980 to 2008, 96% of interceptions of *A. glabripennis* were on wood packaging material, as opposed to on live trees. ISPM15 has been adopted since 2002 and was most recently revised in 2018. It requires that imported wood packaging material is treated to reduce the risk of live quarantine organisms being present (see Appendix B for details). The emergency measures for *A. glabripennis* (EU, 2015) also require that specified wood material, other than wood packaging material, from host plants of the beetle must be heat treated and abide by other restrictions. While these measures minimise the risk of the beetle being introduced via wood material, interceptions of *A. glabripennis* on wood packaging have continued, particularly from China (Eyre and Haack, 2017). An FVO audit of Chinese measures in 2013 showed that the controls applied were not sufficient to ensure wood packaging material exported to Europe was being treated as required in ISPM15 (EU, 2013). Longhorn beetles have also been intercepted from Europe, other Asian countries, Africa, Australasia and the Americas since the introduction of ISPM15 (Eyre and Haack, 2017).

2.4. There have been 10 interceptions of *A. glabripennis* in Great Britain since 1995, all on either wood packaging material or dunnage, with 6 occurring since the introduction of ISPM15 (Europhyt, 2017). An outbreak of *A. glabripennis* was also confirmed in the UK from Kent in March 2012. By July 2012, 66 infested trees had been detected and over 350 live larvae recovered from these trees. Over 2,000 trees were cut down as part of eradication efforts. This included all trees showing signs of infestation, and the main hosts within the infestation zone (Straw *et al.*, 2016). Surveys for the beetle have been carried out annually at the outbreak site, but no beetles were found after 2012, and the outbreak has since been declared eradicated (EPPO reporting service, 2021e).

3. Risk assessments

3.1. *Anoplophora glabripennis* has an unmitigated and mitigated UK Plant Health Risk Register score of 80 and 40, 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=1786).

3.2. A pest risk analysis was carried out by MacLeod *et al.* (2002), following the establishment of the beetle in the US. The PRA assessed the risk posed by the beetle to EU countries, and concluded that it could enter, establish and cause considerable damage to a number of hosts in Europe, particularly in the south.

4. Actions to prevent outbreaks

4.1. *Anoplophora glabripennis* 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. Further pest and host specific requirements are listed in Schedule 7. *Anoplophora glabripennis* is also a GB Priority Pest meaning it is a GB quarantine pest which has been assessed to have the most severe potential economic, environmental and social impacts to GB.

4.2. *Anoplophora glabripennis* is an EU Union Quarantine Pest and is therefore prohibited from being introduced into, or spread within the Union Territory. It is also subject to EU emergency measures (Commission Implementing Decision 2015/893).

4.3. *Anoplophora glabripennis* is an A1 listed pest for the EPPO region and is therefore recommended for regulation by EPPO member countries.

4.4. General measures listed in ISPM 15 are in place to prevent the entry of wood boring pests.

4.5. The Plant Health Service (including the Animal and Plant Health Agency (APHA), Defra, Fera Science Ltd. and Forestry England) should be aware of the measures described in this plan and be trained in responding to an outbreak of *A. glabripennis*. It is important that capabilities in detection, diagnosis, and risk management are available.

5. Response activities

Official action to be taken following the suspicion or confirmation of an interception of *A. glabripennis*

5.1. If *A. glabripennis* is suspected by the Plant Health and Seeds Inspectorate (PHSI) or Forestry Commission (FC) to be present in a consignment moving in trade, the PHSI or FC 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) or Forest Research, Alice Holt Lodge, Wrecclesham, Farnham, GU10 4LH (0300 067 5600), in a sealed bag or container, within at least two other layers of containment, which are not liable to be crushed during transit. Damaged eggs, larvae or pupae should be submitted in tubes of 70% ethanol to prevent further degradation.

5.2. In instances where either live beetles or signs of live beetles are confirmed, the inspector shall determine the level of plant health risk in the circumstances taking into account the weather conditions, the time of year and the likelihood of the pest escaping and require 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 be covered to prevent insect escape.

5.3. When an infestation of *A. glabripennis* is confirmed, the PHSI or FC should advise the client of the action that needs to be taken by way of an official notice. The consignment should be destroyed by either wood chipping, incineration or deep burial.

5.4. Where there is a high risk of escape before destruction, fumigation may be used under guidance from the Defra Risk and Horizon Scanning team.

5.5. A UKPHINS (UK Plant Health Interception Notification System) notification should be made upon confirmation of an interception of live *A. glabripennis.* 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.

5.6. 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 *A. glabripennis*. Details of recent past and future consignments from the same grower/supplier should also be obtained.

5.7. A pest alert to raise awareness of *A. glabripennis* and its symptoms should be distributed to packers/processors and importers where *A. glabripennis* has been found, and to those in the local area and those associated with the infested premises.

The pest alert is available on the Plant Health Portal (https://planthealthportal.defra.gov.uk/pests-and-diseases/pest-and-disease-alerts/notifiable-pests/ ALB-poster-for-PHSI-3.pdf).

5.8. For finds of *A. glabripennis* when the chances of establishment are minimal, such as on imported materials at ports or inland within a warehouse, surveillance should be carried out as set out in point 5.24. However, finds of *A. glabripennis* in the wider environment will need to be treated as suspect outbreaks and investigated as in point 5.9.

Official action to be taken following the suspicion of an *A. glabripennis* outbreak

5.9. 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. Where appropriate, the OTG will also decide who will be the control authority, and the control authority will then nominate an incident commander. An Incident Management Team (IMT) meeting, chaired by the Incident Commander, will subsequently convene to produce an Incident Action Plan (IAP). See the *Defra Generic Contingency Plan for Plant Health in England* for full details.

5.10. The OTG will determine the 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, an infestation of *A. glabripennis* suspected in a tree is likely to be given an amber alert status. An amber alert status refers to a serious plant pest/disease with potential for relatively slow, but extensive geographical spread leading to host death and/or major economic, food security or environmental impacts.

Restrictions on movement of material

Wood packaging material

5.11. If *A. glabripennis* is suspected to have emerged from wood packaging materials (WPM) at an inland site, all the WPM from the same consignment should be placed on hold pending further investigation.

Nursery or garden centre

5.12. If *A. glabripennis* is suspected at a nursery or garden centre, all host plants should be placed on hold pending further investigation.

Wider environment

5.13. If *A. glabripennis* is suspected in a tree or is found free living in the wider environment, all wood material that could potentially host the beetle, including living or felled trees, plant parts, such as branches and firewood, and other wood products, within a radius of at least 100 m should not be moved out of the zone pending further investigation.

Preliminary trace forward / trace backward

5.14. If an infested consignment or tree is considered as being the source of the suspect outbreak, investigations regarding the origins of infested consignments will be undertaken to locate other related and therefore potentially infested consignments of products, WPM, or trees moving to and from the site. For findings in the wider environment, where no trace forward or backward can be done, the most likely source should be identified and investigated.

Confirming a new outbreak

How to survey to determine whether there is an outbreak

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

- location of the find – if found on commercial or private premises this should include the name of the business or householder, the postal address and other contact details that are available (such as phone numbers including mobile numbers and email addresses). For street trees/shrubs, the location information should include the address of the nearest domestic or commercial property to the tree(s)/shrub(s). It will also be necessary to find out the name and contact details of the appropriate department in the local authority. If possible, a GPS should be used to provide a ten-figure grid reference.
- the number and life stages of any *A. glabripennis* found, plus the number and a description of any pest symptoms. Any dead or alive eggs, larvae, pupae or adult *A. glabripennis* should be collected and sent to the Fera Science Ltd at Sand Hutton or Forest Research at Alice Holt (see point 5.1)
- a description of the infested host or hosts, including the host species, plus approximate dimensions (diameter at breast height, approximate height), age/maturity, and general condition. The level of infestation should also be recorded such as the number of exit holes present.
- a description of other trees/shrubs in close vicinity (i.e. their species and approximate size)
- details of how the pest was first reported or noticed

- available information on recent movements of possibly infested trees, shrubs or logs or pallets
- any available information on what the original source of the pest may have been e.g. whether there are any importers of heavy machinery from Asia, stone importers or building developments that may have used granite/slate.

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

5.16. Further to information gathering, surveys of other host plants and host wood should be carried out to confirm the extent of the infestation e.g. in surrounding gardens, parks etc. This should include samples and photographs of suspect plants and wood where possible. This initial survey will be used to determine if it is an isolated finding or an established outbreak.

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

Sampling

5.18. Any eggs, larvae, pupae or adults or symptomatic wood samples found during the course of inspection, survey or tree removal operations, should be submitted by the PHSI or FC to Fera Science Ltd. or Forest Research as in point 5.1.

5.19. Suspect trunks and large branches should be cut into sections to allow a thorough inspection for symptoms before being disposed of.

Diagnostic procedures

5.20. The morphological identification of *A. glabripennis* larvae can be carried out with the aid of voucher specimens in collections and all the currently available references including Duffy (1953), Duffy (1968), Bense (1995) and Pennacchio *et al.* (2012). Although, Duffy (1953) is primarily for beetles present in the UK, it may be used to confirm that specimens are not a native species.

5.21. The morphological identification of *Anoplophora* sp. adults can be carried out with reference to voucher specimens and the descriptions provided by Lingafelter and Hoebke (2002). Bense (1995) provides comprehensive keys to the native European fauna that may also be used to confirm that a specimen is not a native species.

5.22. If considered necessary, it is possible for the morphological identifications to be supported by molecular methods as molecular sequence data is available.

Criteria for determining an outbreak

5.23. An outbreak will be declared if there is evidence showing that *A. glabripennis* may have established a population within the wider environment, separate from the material in which the pest has been moved to the UK. For example:

- An adult beetle and fresh exit hole is found on a mature tree anywhere in England. In this situation, an outbreak of *A. glabripennis* will be declared.
- An adult beetle found on wood packaging material at a stone importer and a fresh exit hole is found in the wood packaging. In this case, an outbreak will **not** be declared.

5.24. Where an outbreak is not declared and establishment of the beetle is not expected, but there is a chance that adult *A. glabripennis* may have escaped and dispersed, and could have colonised trees,

- Immediate eradication of any beetle found and destruction of infested material to exclude the possibility of spread.
- Monitoring within a radius of at least 1 km around the finding for at least one life cycle of the beetle plus an additional year including monitoring in at least four consecutive years. Surveillance during the first year will be more regular and intensive.
- Trace forward and backward of associated material, including inspection and targeted destructive sampling as appropriate.
- A pest alert to raise awareness of *A. glabripennis* and its symptoms should be distributed to those in the local area and those associated with the infested premises.
- Further measures which contribute to the eradication of the organism should be carried out in line with ISPM 9: guidelines for pest eradication programmes (https://www.ippc.int/en/publications/611/), which provides guidance on information gathering, surveillance, containment and treatments, and ISPM 14: the use of integrated measures in a systems approach for pest risk management, which provides control options for pre-planting, pre-harvest, harvest, post-harvest and during transport, and provides guidance on developing a systems approach based on these options.

Official Action to be taken following the confirmation of an outbreak

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

Communication

5.26. The IMT will assess the risks and communicate details to the IPPC 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.

5.27. Information on the outbreak will be communicated to residents and businesses inside and outside the infested zone using various media formats e.g. leaflets, official posters, articles in local newspapers, appropriate websites, local radio etc. Consideration should also be given to the use of social media such as a ‘Facebook’ or ‘Twitter’ page where members of the public can post questions relating to the outbreak.

5.28. Prepared material is already available, including the pest alert, factsheet on differentiating *Anoplophora* longhorn beetle damage from that of native wood-boring insects, and information on the Observatree website (https://www.observatree.org.uk/portal/asian-longhorn-beetle/).

5.29. When an outbreak is considered likely to have a limited public impact, as appropriate APHA and/or FC’s media and communication teams will coordinate external communications. Example scenarios could include an outbreak in a nursery surrounded by a low urban density or in an urban area where there are few host plants resulting in limited felling activity. If the outbreak occurs in an area that is likely to cause significant media and public interest, for example an inner city nature reserve/public park with a high density of trees that require felling, 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.

5.30. 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.

5.31. 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

5.32. Once an outbreak has been confirmed, a demarcated area must be established around known infested trees. This will include two zones:

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

- The **buffer zone**, which will initially be at least 2 km from the infested zone, with the exact delimitation based on the biology of the beetle, the level of infestation, the distribution of host plants and evidence of establishment. This can be reduced to an area within 1 km of the infested zone following surveys, if considered by the IMT that the eradication of the beetle is possible.

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

5.34. Plants within the infested and buffer zone should be surveyed for signs of the beetle, as described in 5.38-5.44.

5.35. If it is considered possible that the beetle has been spread to other destinations, such as those with a history of receiving potentially infested trees or wood from within the demarcated area e.g. firewood merchants or local authority green waste disposal sites, then these areas should be surveyed. These zones should be treated as if they are part of the buffer zone.

5.36. The demarcated area should be adjusted in response to further findings. If *A. glabripennis* is found within an area outside the infested zone, this should subsequently be designated as infested.

5.37. Movement of potentially infested material out of the demarcated area should be prevented. The PHSI or FC will contact garden centres, nurseries and other traders of host plants, as well as owners/managers/tenants of woodland areas, conservation areas and 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 plants or wood 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

5.38. Priorities for surveying in different areas around the outbreak are listed below. These can be modified by the IMT depending on the specific circumstances of the outbreak. Surveys in different areas may be carried out concurrently.

- The highest priority for surveys will be broadleaved trees and hedgerows within 100 m of known infested trees. These will initially be surveyed by inspectors from the ground with the aid of binoculars.
- The second highest priority is to survey broadleaved trees, hedgerows and wood on or within 100 m of any nurseries selling host plants, firewood merchants or other businesses/organisations that are within the demarcated area and may be moving potentially infested plants or wood out of the demarcated area.
- Thirdly, broadleaved trees within the first 400 m out from the infested zone should be surveyed. It is advisable to survey all or part of this area using tree climbers trained to spot the symptoms of *Anoplophora* because they may detect infestations in trees that have not been possible to detect from the ground. A decision on when and where to use tree climbers will be made by the IMT.
- Lastly, host plants within 400-2000 m of the infested zone. Some of this area, for example the inner area may be surveyed by a systematic survey of all host trees and the rest may be surveyed by surveying just a sample of high risk trees, such as *Acer pseudoplatanus* (sycamores) and *Aesculus hippocastaneum* (horse chestnuts). The areas to be surveyed systematically and by surveying only high risk trees will be determined by the IMT.
- A selection of 'sentinel trees' will also be surveyed on a more regular basis, ideally at least two times per year (in spring/summer and winter). These will be single or groups of trees of the most favoured hosts of *A. glabripennis* selected to have a representation across the demarcated area. These trees could be selected on a circular route around the outbreak site (based on public pathways or other convenient routes), thereby providing a balance between being representative and accessible.

5.39. Inspection of trees could be done as follows:

- Inspection of the whole plant for signs of *A. glabripennis* up to the middle of the crowns, regardless of whether the trees have a clear trunk such as *Betula* and *Acer*, or if they have branches along the entire trunk or have basal suckers, such as *Populus* (Haack *et al.*, 2006).

- Inspection of trees and branches with a diameter of 2.5 cm or more; it is reported that a minimum diameter of 5 cm for egg deposition is required for *A. glabripennis* (Ric *et al.*, 2007).

    - Inspection underneath the tree for signs of frass or prematurely fallen leaves. However, the PHSI's experience of surveying trees for frass in Kent, 2012, was that the process was slow and inefficient, so should be of low priority.

    - Inspection of the trees, branches, and exposed roots for oviposition pits, exit holes, and hollow bark, with the use of binoculars to scan for symptoms higher up in the trees.

    - Inspection under the bark to see larval chambers.

5.40. If suspicious symptoms are seen in a deciduous tree during ground surveys that cannot be dismissed as being likely to be due to another cause, they should be checked by the use of qualified tree climbers trained to spot *A. glabripennis* either by closer visual inspection, the removal of the bark or by cutting down and splitting the infested branch.

5.41. Surveys will be carried out annually and will continue until no beetle has been detected for at least two lifecycles of the beetle (at least six years in UK climate). These surveys will be carried out by ground surveyors and tree climbers, with a specific survey plan developed based on the outbreak situation.

5.42. The first surveys of the demarcated area will be carried out as soon as possible after the outbreak has been discovered. Subsequent surveys will be carried out during the winter or early spring when the trees are not in leaf, as this is considered the best time of the year to detect exit holes and most symptoms of *A. glabripennis* damage in host trees.

5.43. Description and photos of symptoms, and guidance on surveillance can be further found in Ric *et al.* (2007) and on the Observatree website (https://www.observatree.org.uk/portal/asian-longhorn-beetle/).

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

Pest management procedures

5.45. All infested plants and plants with symptoms of the beetle, as well as all host plants within a radius of at least 100 m of any plant found to be infested should be cut down and removed. There is evidence showing that beetles are able to fly greater than 100 m and up to 203 m (Straw *et al.*, 2016), therefore felling of preferred hosts further than 100 m should be considered. This would depend on the outbreak situation (including the extent, age and source of the outbreak) and host distribution in and around the infested zone. If infested plants are found outside the flying period for the beetle, the felling and removal should be carried out prior to the start of the next flying period, but ideally within a short space of time to allow the felled trees to be checked for further signs of infestation which could lead to the need to fell additional trees.

- The removal of host plants will remain the responsibility of the occupier or other person in charge of the premises. Contact information for the Arboricultural Association with their register of qualified tree surgeons and ConFor (Confederation of Forestry Industries) will be provided to enable landowners to identify qualified operatives to carry out removal work. In exceptional circumstances, the removal of trees and shrubs may be carried out by the PHSI or FC.

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

5.46. The radius of the areas described may be adjusted to reflect the density of potential and favoured hosts and the number of beetles, larvae and exit holes that have been found.

5.47. In exceptional cases where the IMT concludes that felling is inappropriate, an alternative eradication measure may be applied offering the same level of protection against the spread of the specified organism.

5.48. Plants and hedgerows should be cut as close as possible to ground level. The cut surface should be examined for signs of *Anoplophora* activity. If signs are found then the stumps should be ground down to a level at which no symptoms are seen or, alternatively, the stumps should be dug up and removed and disposed of appropriately.

5.49. If the removal of stumps could cause unacceptable damage, fine mesh may be used to cover the stumps to prevent the escape of any remaining beetles, and to prevent any re-infestation (van der Gaag *et al.*, 2010; Roselli *et al.*, 2013). The IMT will provide advice on a case by case basis.

5.50. All felled trunks and branches should be cut into sections of a size that can be easily handled, turned over and examined by inspectors before disposal. The outside of the logs and cut ends must be examined for any signs of *Anoplophora* damage. This could include exit holes, frass, cracks in the bark caused by tunneling or oviposition scars. Damage that is considered to potentially be caused by *A. glabripennis* should be checked by cutting thin slivers of wood away from the surface to reveal whether there is any tunneling below, and/or splitting the wood open with a hand axe. An alternative to cutting open suspect logs in the field is to transfer them to a laboratory or other facility set up to carry out this task (e.g. a welfare/office unit). If this option is taken, logs need to be transported within three layers of containment and the laboratory/alternative facility needs to be licensed to hold such materials. Although time consuming this may yield valuable information on the outbreak including, for example, the extent and age of the outbreak.

5.51. The possibility of using foliar insecticide treatments will be considered by the IMT for trees or shrubs within the infested zone if the outbreak is discovered during the potential adult flight period. They could help to prevent further spread of *A. glabripennis* in the year that the outbreak is first discovered. However, they are likely only to be beneficial for heavy infestations of the beetle, where there is a high likelihood of further spread, as treatments have the potential to act as repellents to adult beetles. Prior to any insecticides being used, the risk posed by the insecticides to people and the environment will be assessed. If their negative impact to people and the environment is too great, they should not be used.

- 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.

5.52. After the clearance of trees in the infested area, trap trees (including within hedgerow environments) of an appropriate size may be established within this zone to attract and monitor for *A. glabripennis*. A minimum of six trees will be planted and these will be of an *Acer* spp. such as *A. pseudoplatanus* (sycamore). The trees will be planted in the ground as close as possible to the locations where the infested trees were found, ideally on publicly owned or managed land but always with the prior consent of the person in charge of the land. The trees will be inspected for signs of infestation a minimum of twice a year at the start and end of each summer, but ideally more regularly over the summer period. If signs or symptoms of *A. glabripennis* are seen, these trees will be destructively sampled.

Disposal plan

5.53. During the *Anoplophora* flight period (1st June until 30th October based on emergence between June and October in the USA (USDA-APHIS 2008) and first emergence in July in Hebei and Beijing (Li and Wu 1993)), all felled trees, parts of trees from the infested area should be destroyed/processed as soon as possible after it has been inspected, within a maximum of one week. Options for destruction/processing are:

- Chipping to dimensions of not more than 15 mm in thickness and width (experimental evidence from the USA suggests that *Anoplophora* juveniles will not survive in this material). This would be the most appropriate method of disinfesting shrubs, small trees and branches. It may be possible to leave the chipped material in situ but away from footpaths etc. (e.g. where large areas are infected) under an Environment Agency exemption which currently permits a maximum of 250 cubic metres in any one deposit (check the Environment Agency for current details, similarly for burning - https://www.gov.uk/topic/environmental-management/environmental-permits).
- 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. NB: it will often not be practical to burn whole trees or large sections, other than those with small diameters e.g. branch wood.
- Moved under containment to a location known and approved by the PHSI or FC. For example, material with no visible signs of infestation could be indelibly marked, then moved to a new location in *Anoplophora* spp. proof containers (e.g. steel shipping containers) and dealt with once conditions are too cool to permit adult activity.

5.54. Between 1st November and the 31st May, unprocessed logs may be indelibly marked then moved out of the infested area under official notice if they are going to a site where they will be processed by one of the following methods before the following flight season:

- Wood chipping – chipping to dimensions of not more than 15 mm in thickness and width.
- Burning or incineration.

5.55. Other methods of disposal, such as deep burial of non-hazardous waste at a local authority approved landfill site, or use as biomass, may be considered on a case by case basis.

5.56. 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.

5.57. 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.

5.58. Landowners need to ensure that any clearance complies with Habitat Regulations. If needed, permissions can be sought to undertake emergency activities e.g. felling. Further information may be obtained from Natural England or the FC (the latter being the lead authority for all forestry activity).

Replanting

5.59. No host plants will be planted in the demarcated area during the outbreak, except for trap trees.

5.60. There are no records of the following species being hosts and they would be suitable for planting in the demarcated area: *Ailanthus altissima* (Tree of Heaven), *Castanea* (sweet chestnut), *Cornus* (Dogwood), *Crateagus* (hawthorn), *Euonymus* (spindle), *Gleditsia* (honey locust), *Hamamelis* (witch hazel), *Ilex* (holly), *Juglans* (walnut), *Magnolia*, *Ostrya* (hop hornbeam), *Quercus robur* (English/Pedunculate oak), *Quercus petraea* (Sessile oak), *Rhamnus* (buckthorn), *Sambucus* (elder), *Syringa* (lilac), *Viburnum*. Any coniferous species would also be safe to plant.

6. Criteria for declaring eradication / change of policy

6.1. The outbreak will be declared eradicated if the pest is not detected for a period covering at least two lifecycles of *A. glabripennis* and will be at least six years long in the UK.

7. Evaluation and review of the contingency plan

7.1. This pest specific contingency plan should be reviewed regularly to consider 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 *A. glabripennis* 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 *Anoplophora glabripennis*

Identity

PREFERRED SCIENTIFIC NAME	AUTHOR (taxonomic authority)
Anoplophora glabripennis	(Motschulsky,1853)

CLASS: Insecta
ORDER: Coleoptera
SUBORDER: Polyphaga
SUPERFAMILY: Chrysomeloidea
FAMILY: Cerambycidae
SUBFAMILY: Lamiinae

SYNONYMS

Cerosterna glabripennis Motschulsky 1853
Cerosterna laevigator Thomson 1857
Anoplophora nobilis Ganglbauer 1890
Malanauster nobilis Ganglbauer 1890
Melanauster luteonotatus Pic 1925
Melanauster angustatus Pic 1925
Melanauster nankineus Pic 1926
Anoplophora glabripennis Breuning 1944
Malanauster glabripennis var. *laglaisei* Pic 1953

COMMON NAMES

Aziatische boktor (Dutch)
Loofhoutboktor (Dutch)
Asian long-horned beetle (English)
Asian longhorn beetle (English)
Basicosta white-spotted longicorn beetle (English)
Starry sky beetle (English, translation from China/Japan)
Starry night beetle (English, translation from China/Japan)
Capricorne asiatique (French)
Coléoptère de ciel étoilé (French)
Longicorne asiatique (French)
Asiatischer Laubholzkäfer (German)
Tarlo asiatico del fusto (Italian)

Besouro-do-céu-estrelado (Portuguese)
Азиатский усач (Russian)
Азиатский усач (Russian)
Escarabajo asiático de antenas largas (Spanish)
Escarabajo asiático de cuernos largos (Spanish)
Asiatiska långhorningarna (Swedish)

Notes on taxonomy and nomenclature

The genus *Anoplophora* currently contains 37 species (Lingafelter and Hoebeke, 2002; Xie *et al.*, 2012). *Anoplophora glabripennis* is part of a complex of four species within this genus, which also includes *A. freyi*, *A. flavomaculata* and *A. coeruleoantennatus* (though the latter species is only suspect taxonomically and may simply be individual variation of another species) (Wu and Jiang, 1998).

In the early 21st century, the relationship between the two putative species within *Anoplophora*, *A. glabripennis* and *Anoplophora nobilis* (Ganglbauer) was investigated by Gao *et al*. (2000) and Tang *et al*. (2004). A study of external morphology showed that they have the same microreticulations at the elytral base, although there is variation in colour of the elytral spots (i.e. white in *A. glabripennis* and yellow in *A. nobilis*) (Luo *et al*., 2000). *Anoplophora glabripennis* and *A. nobilis* are generally found in the same areas and they utilize similar host tree species (An *et al*., 2004). The peroxidase and esterase isoenzymes of these two species were compared and no significant differences were found (Zhou *et al*., 1995; Tang and Zheng, 2002). Results obtained from studies using random amplified polymorphic DNA also suggested that they belong to the same species (An *et al*., 2004). A contrasting result was obtained by Kethidi *et al*. (2003), where two pairs of sequence characterized-amplified-region primers were found to differentiate *A. glabripennis* from several other closely-related cerambycids, including *A. nobilis*. To solve this uncertainty, cross-mating experiments were conducted between *A. glabripennis* and *A. nobilis*. The results obtained showed that the F1 generation could produce a viable F2 generation (Gao *et al*., 2000). Therefore, *A. nobilis* and *A. glabripennis* are now regarded as two forms of *A. glabripennis*, in agreement with Lingafelter and Hoebeke (2002).

Biology and ecology

Life history

Existing reviews

A detailed description of *Anoplophora glabripennis*'s biology is provided by Lingafelter and Hoebeke (2002, p16-26), and a review of the taxonomy, distribution, basic biology, behaviour, ecology and management of *A. glabripennis*, including information that is available in the extensive Chinese literature is provided by Hu *et al.* (2009). More recently, interceptions, international spread and management have been reviewed by Haack *et al.* (2010).

Adult emergence and longevity

In northwest China (Yinchuan, Ningxia Province), *Anoplophora glabripennis* adults emerge from infested trees and are present in the field from April or May to October, with an emergence peak in July. In New York City and Chicago, adult *A. glabripennis* were recorded from July to December (Haack *et al.*, 1997; 2006). While in northern Italy, beetles emerged from late May, and 90% of emergence was completed by late July (Faccoli *et al.*, 2015).

The initiation of adult emergence is influenced by the accumulated annual temperature (Zhao and Yoshida, 1999). Temperature also has a significant effect on the time it takes for teneral adults (adults newly emerged from pupal cases) within a host to initiate boring and exiting the host. Using infested wood blocks at three constant temperatures (20, 25 and 30ºC), Sanchez and Keena (2013) found adults required more than a week to progress from eclosion (when adults emerge from pupae) to emergence through a 7 mm block of maple wood. Specifically, they found adults took 12 days at 20°C, 9 days at 25°C and 8 days at 30°C. Temperature was also thought to play a role in the emergence of beetles in the Paddock Wood outbreak in 2012, with tree ring and degree day calculations estimating emergence late in the year, from mid-August onwards in the UK (Straw *et al.*, 2015).

Studies in China showed that male adults live for 3–50 days, and females live for 14–66 days (Li and Wu, 1993), whereas laboratory studies at 25°C in the USA reported a longevity of approximately 80 days for males and 100 days for females (Keena, 2006). Adults feed throughout their lives on leaves, twigs or the tender bark of the host trees, causing damage to living trees (Li and Wu, 1993).

Host location is dependent on both visual and olfactory cues. Lyu *et al.* (2015) showed that adult beetles were more attracted to the visual and olfactory cues of the host plant *Acer negundo*, than the non-host plants *Sabina chinensis* and *Pinus bungeana*, and that visual and olfactory cues in combination were more attractive than either cue alone. Although, visual cues were more attractive than olfactory cues, indicating that visual cues are more important.

Reproduction and egg laying

The sexes locate each other by a combination of aggregation pheromones and visual cues (Zhang *et al*., 2003). Long range pheromones are produced by males, trail pheromones are produced by females, and visual cues and contact pheromones provide confirmation of a mate.

Long range pheromones: Studies have been conducted to characterize the pheromones of A. glabripennis. Preliminary experiments have shown that male orientation is influenced by volatiles released by females (Li et al., 1999), although these substances were not chemically identified. Further investigations revealed that two dialkyl ether volatiles, 4-(n-heptyloxy)-butanal and 4-(n-heptyloxy)-butan-1-ol, are potential male-produced pheromones in this species (Zhang et al., 2002). They are secreted by males in a ratio of 1:1 and they elicit strong Electroantennogram (EAG) responses in both males and females. Olfactometer experiments showed that they were significantly attractive to adults, although they do not seem to be involved in sex recognition (Zhang et al., 2002). A third compound, (3E, 6E)-alpha-farnesene, has since been identified in males, which increases the attraction of both males and females compared with 4-(n-heptyloxy)-butanal and 4-(n-heptyloxy)-butan-1-ol alone (Crook et al., 2014).

Trail pheromones: Recently, Hoover *et al.* (2014) discovered that females produce a trail sex pheromone to facilitate mate finding behaviour in males once they are on the same tree. This pheromone is left on the surface of the tree as the female walks over it and is detected by the labial palps of the male (Graves *et al.*, 2016). Males were only observed to respond to the pheromone following contact, suggesting that olfaction is not involved, though further study is required to confirm this (Graves *et al.*, 2016).

Contact pheromones: GC-MS analysis of female cuticular extracts showed that five monounsaturated compounds were consistently more abundant in females than in males (Zhang *et al*., 2003). These compounds were identified as the alkenes (*Z*)-9-tricosene, (*Z*)-7-pentacosene, (*Z*)-9-pentacosene, (*Z*)-7-heptacosene and (*Z*)-9-heptacosene, with a relative ratio of 1:2:2:1:8. Males attempted to mate when contacting a surface coated with a synthetic mixture of these compounds, indicating that the blend effectively elicits copulatory behaviour in males (Zhang *et al*., 2003). Recently, a contact sex pheromone of *A. chinensis* (syn. *A. malasiaca*) was discovered from the ether extract of 200 females. Three male-active compounds have been newly characterized as a group of *γ* -lactones called gomadalactone A, B and C (Mori, 2007; Yasui *et al*., 2007). It is not known whether chemicals similar to the gomadalactones might also occur in *A. glabripennis*.

On emergence, females can copulate, although their ovaries are immature and feeding is necessary for ovarian maturation; laboratory studies have estimated the female maturation period to last 9 – 15 days after emergence. (Keena, 2002; Smith *et al*., 2002). Adult males have mature spermatozoa before emergence, and feeding is necessary only to sustain their normal activity (Li and Liu, 1997).

Adults are least active early in the day and become more active late in the day (Morewood *et al*., 2004). Keena and Sanchez (2007) reported that the reproductive behaviours of *A. glabripennis* is typical of diurnally active species of the subfamily Lamiinae. Both sexes mate repeatedly and with different partners (Morewood *et al*., 2004).

Most females lay 25–40 white eggs under natural conditions in China; usually, one egg is deposited in each oviposition site (Li and Wu, 1993). Under laboratory conditions, the highest recorded average fecundity was 66.8 eggs per female at 25˚C, and estimates from the USA suggest that, in nature, fecundity may vary in the range of 30 – 178 viable eggs per female (Keena, 2002; 2006). Fecundity is positively correlated with beetle body size and negatively correlated with beetle age. Fecundity is also strongly affected by host tree, with eggs per female ranging from 45.9 for the black willow (*Salix nigra* Marshall) to 193.3 for Norway maple (*Acer platanoides* L.) (Smith *et al*., 2002). Similarly, the oviposition rates differed based on female food, with averages ranging from 1.80 eggs / day for A. *platanoides* to 0.54 eggs / day on S. *nigra* (Smith *et al*., 2002).

In nature, females select an oviposition site based on stem diameter and bark thickness of the host tree but bark thickness appears to play the more important role (Zhao *et al*., 1997). On cut wood, oviposition has been found to be negatively correlated with bolt surface area, bolt diameter and bark thickness (Smith *et al*., 2002). During the UK outbreak, Straw et al. (2014) found larvae, pupae and exit holes in stem and branches between 2.1 and 61.5 cm in diameter, but with the majority being found in sections between 4 and 10 cm in diameter. In addition, *A. glabripennis* prefers host tree species with rough bark and leaves without epidermal trichomes and glands (Yang *et al*., 1997). Based on infested trees in China and Chicago, *A. glabripennis* usually begins attacking trees near the base of the crown, on both the upper trunk and lower parts of major branches (Haack *et al*., 2006). However, on *Populus* trees in China where branches occur all along the trunk, *A. glabripennis* commence attacks on the lower trunk. Beetles can attack the same tree, year after year, by laying eggs further down toward the roots in successive years; however, studies documenting and investigating female decisions to continue ovipositing in the same tree rather than move to a different tree are not known.

Development

Life cycle duration

In China, *A. glabripennis* requires one or two years to develop from egg to adult and generally overwinters as a larva, although it has been found on rare occasions to overwinter as an egg or pupa (Li and Wu, 1993; Haack *et al*., 2006). Voltinism (number of generations per year) may vary as a function of local climatic conditions, and a significant correlation has been established with latitude (Figure 1). In Inner Mongolia (northern China, 42° north), a single generation takes two years to develop, whereas in Taiwan (24º north) one generation per year has been documented (Li and Wu, 1993). In between these areas, for example in Liaoning, Shangdong, Henan and Jiangsu Provinces, which spread from around 42° to 32° north, *A. glabripennis* develops within one or two years (Hua *et al*., 1992). In Shandong Province (central-eastern China), approximately 90% of individuals complete a generation in 1 year. Further south in Jiangsu, 98% are univoltine (one year for a generation) and 2% bivoltine (two years per generation) (Hua *et al*., 1992). It has been estimated that overall in China about 80% of individuals can complete their development within 1 year and < 20% require 2 years. However, the time to complete one generation may vary among populations in a single area, depending on the type of host in which the larvae develop.

Under field conditions, 1,264 degree-days (DD) above a threshold of 13.4˚C are required to complete development (Yang *et al*., 2000). Under laboratory conditions, the accumulated DD and the lower development temperature threshold for egg, first and second instar larvae were estimated as 250 DD at 10.2°C, 160 DD at 11.7°C and 232 DD at 11.4°C, respectively (Zhang *et al.,* 1995).

Working at seven constant temperatures (5, 10, 15, 20, 25, 30, and 35°C), Keena (2006) reported the adult survival, reproduction, and egg hatch of *A. glabripennis* from two US populations (Chicago and New York). Nonlinear regressions were used to estimate the temperature optimum and thresholds for each life history parameter. The results are summarized in Table 1.

Figure 2. Typical generation time of *Anoplophora glabripennis* in China.
(Source: http://www.sacu.org/provmap.html)

Table 1. Lower temperature threshold (minimum), optimum temperature and upper temperature threshold (maximum) for *Anoplophora glabripennis* (Keena, 2006)

Feature	Minimum temperature threshold (ºC)	Optimum temperature (ºC)	Maximum temperature threshold (ºC)
Adult survival: ♀ ♂	-3 -2	18	39 38
Fecundity: New York Chicago	11 14	23 24	34 35
Oviposition	10	24	35
Egg hatch	10	23 - 29	32

Building on Keena (2006), Keena and Moore (2010) examined the effect of temperature on *A. glabripennis* development at eight constant temperatures (5, 10, 15, 20, 25, 30, 35 and 40°C). The temperature threshold for development of each life stage was derived from the rate of development at each temperature. The estimated lower threshold temperature for development of instars 1-5 and the pupal stage was near 10°C and was near 12°C for instars 5-9 (Keena and Moore, 2010). For temperatures between 10 and 30°C, the researchers reported a linear relationship between temperature and the rate of development. Larval development was inhibited at over 30°C, and all instars failed to develop at 40°C (Keena and Moore, 2010). The authors point out that almost all development of *A. glabripennis* occurs in the heartwood of hosts. As such, the temperature experienced by larvae and pupae can be very different from the ambient air temperature recorded at meteorological recording stations. The internal temperature of a tree is proportional to factors such as air temperature, the location of a tree, the depth of wood, wood density, solar exposure, seasonality and wind speed. At night, the stored thermal radiation keeps wood at a higher temperature than ambient air temperature. Differences in air temperature and that in the phloem can be 10°C or higher, although a difference of 2°C would be more typical. Therefore, if a model is developed based on air temperature, the authors suggest that modellers add at least 2°C to air temperature.

Modelling systems such as CLIMEX have been used to predict the potential distribution of *A. glabripennis* (e.g. MacLeod *et al.*, 2002). CLIMEX has also been used to make predictions about the rate of development of *A. glabripennis* in the UK (see Figure 2). According to this model, *A. glabripennis* would be expected to have a lifecycle of 2 years in south-east England and in some locations along the south coast of England, while further north, the life cycle would be expected to take three or more years. Straw *et al.* (2015), on the other hand, concluded that *A. glabripennis* would generally take 3 years to complete development in Paddock Wood, Kent, in south-east England, particularly in cooler years. This was based on the finding of two cohorts of well-established larvae from the outbreak in 2012, which correspond to larvae in their second and third year of growth. It should be noted, however, that there were some larvae that were intermediate in size between the two cohorts, which suggests that either these larvae were developing at different rates or there were some larvae which were able to complete their life cycle in 2 years.

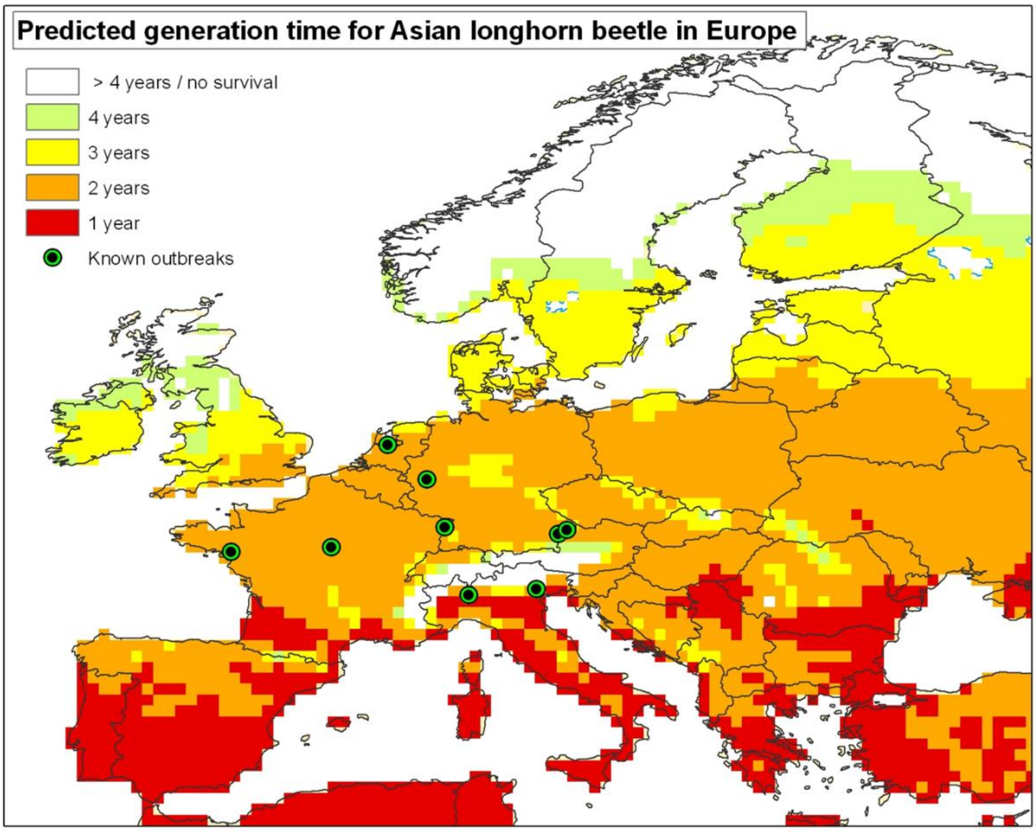

Figure 3. Modelled generation time for *Anoplophora glabripennis* in Europe (CLIMEX model by D. Eyre, DEFRA, available in MacLeod et al. (2012)). Outbreaks in this map are no longer up to date.

Behaviour

After eggs are laid, the inner part of the bark surrounding the oviposition site degrades, and following egg hatch, the larvae begin to feed on the decayed phloem. As they progressively move under the bark, away from the oviposition site, the second-instar larvae feed primarily on the healthy phloem/cambium and feed a little on the nearby xylem.

Larvae develop through several instars and most individuals overwinter as larvae. The supercooling point (when internal fluids freeze) of the larvae initially decreases as temperatures lower, before rising again as freezing temperatures occur (Feng *et al.*, 2016a). Larvae are able to tolerate freezing temperatures, as shown in US laboratory trials, where female larvae recovered from being kept at -40^{o}C (below their supercooling point, which averaged -25.8°C) for 24 hours and went on to develop, mature and successfully reproduce (Roden *et al*., 2008). Interestingly, the overwintering capacity of larvae may differ depending on the host plant and by location. Feng *et al.* (2016b) found that the SCP and concentration of low molecular weight sugars and polyols (known to be involved in low temperature tolerance) differed significantly between larvae which fed on *Populus opera*, *Populus tomentosa*, and *Salix matsudana*. While, Feng *et al.* (2014) found the SCP of *A. glabripennis* to differ between five populations in China (Yili, Yanchi, Wulateqianqi, Beijing, and Dezhou).

The early larval stages eat approximately 4 cm^2 of phloem when tunneling laterally under the tree bark, before starting to tunnel into the xylem in the late third or early fourth instar. The larval galleries are at first horizontal and slightly curved but galleries later turn upward (i.e. usually away from the roots). As the larvae tunnel, they expel frass from the initial oviposition site. Field studies have shown that one larva is capable of destroying approximately 1000 cm^3 of timber before pupation (Yan and Qin, 1992). At pupation, each larva creates a chamber near the outer bark. The prepupal stage (average developmental period of 21.8 days) is followed by a pupal stage (average 19.6 days). Adults subsequently emerge and begin to melanize (increase the concentration of melanin and darken), before spending several days resting prior to chewing a 6 – 18 mm exit hole (Lingafelter and Hoebeke, 2002).

Mortality

Zhao *et al*. (1993) developed a life table for natural populations of *A. glabripennis* on two *Populus* spp. (*P. pekinensis* and *P. dakuanensis*). Natural enemies, mechanical damage and low temperature were key mortality factors. The mortality rate for all life stages combined was 62–65%, with the early larval stage being the most susceptible, incurring 38-47% of the mortality. The mortality rates of the different stages of *A. glabripennis* were also tested under a range of environmental conditions by Tang *et al*. (1996), who demonstrated that eggs and first-instar larvae were the most susceptible stages of those studied. In this case, bacterial or fungal infections played an important role in reducing larval survival.

Hosts/crops affected

Anoplophora glabripennis is polyphagous, with certain hosts, such as *Acer*, *Populus*, *Salix* and *Ulmus* being well documented in the field and in laboratory testing (CABI, 2017). Others are less preferred, and in the USA, plants of *Celtis*, *Malus*, *Pyrus* and *Tilia* have been found with adult feeding damage or oviposition but have not supported the full development of the beetle (Haack *et al.*, 2006). In Chicago street trees, for example, the infestation rate of *Acer* and *Ulmus* was significantly higher than their actual proportion in the tree population, whilst *Aesculus*, *Celtis*, *Fraxinus*, *Pyrus* and *Tilia* were underrepresented (Haack *et al.*, 2006). Likewise, *Acer* and *Ulmus* were preferred in Northern Italy, along with *Salix* and *Betula*, accounting for 97.5% of infested trees, as compared with *Aesculus*, *Populus* and *Prunus*, which only accounted for 2.5% (Faccoli and Favaro, 2016). While there seems to be a preference for certain host genera, it should be noted that there is great variation in the susceptibility of, or preference for, different species within genera, as has been recorded for *Populus* (Li and Wu, 1993).

During the Paddock Wood outbreak in Kent, UK, *A. glabripennis* showed a strong preference for sycamore (*Acer pseudoplatanus*). Twenty-six percent of plants within this species was attacked by the beetle, compared with only 3% of field maple (*Acer campestre*), poplars (*Populus* spp.), willows (*Salix* spp.) and birch (*Betula pendula*) (Straw *et al.*, 2014).

Table 2. Host plants of *Anoplophora glabripennis*. Where possible, these plants were assigned into one of four categories based on van der Gaag and Loomans (2014). Category I refers to plant species on which A. glabripennis is able to complete its full lifecycle

Host plant	Type	Reference
***Acer* (maples)**	Category I	CABI (2017); EU (2015); van der Gaag and Loomans (2014)
Aesculus	Category I	van der Gaag and Loomans (2014)
Albizia (mimosa)		EU (2015)
Albizia julibrissin	Category I	
***Alnus* (alders)**	Category III	CABI (2017); EU (2015); van der Gaag and Loomans (2014)
***Betula* (birches)**	Category I	CABI (2017); EU (2015); van der Gaag and Loomans (2014)
***Buddleja* (butterfly bush)**		EU (2015)
***Carpinus* (hornbeam)**	Category III	van der Gaag and Loomans (2014)
***Celtis* (hackberry)**	Category IV	EU (2015); van der Gaag and Loomans (2014)
***Cercidiphyllum* (katsura)**	Category I	EU (2015), van der Gaag and Loomans (2014)
***Corylus* (hazel)**		EU (2015)
***Corylus colurna* (Turkish hazel)**	Category I	van der Gaag and Loomans (2014)
***Elaeagnus* (silverberry)**		EU (2015)
Elaeagnus angustiflolia	Category I	van der Gaag and Loomans (2014)
***Fagus* (beech)**		EU (2015)
Fagus sylvatica	Category I	van der Gaag and Loomans (2014)
***Fraxinus* (ashes)**	Category I	CABI (2017); EU (2015); van der Gaag and Loomans (2014)
***Hedysarum* (sweetvetch)**	Category IV	van der Gaag and Loomans (2014)
Hibiscus		EU (2015)
Hibiscus syriacus	Category III	van der Gaag and Loomans (2014)

***Hippophae* (sea buckthorns)**	Category IV	van der Gaag and Loomans (2014)
Koelreuteria		EU (2015)
***Koelreuteria paniculata* (golden rain tree)**	Category I	van der Gaag and Loomans (2014)
***Liquidambar* (sweet gum)**	Category IV	van der Gaag and Loomans (2014)
***Liriodendron* (tuliptree)**	Category IV	van der Gaag and Loomans (2014)
***Malus* (apples)**		CABI (2017); EU (2015)
***Malus domestica* (apple)**	Category I	van der Gaag and Loomans (2014)
Melia	Category IV	EU (2015); van der Gaag and Loomans (2014)
Morus		EU (2015)
***Platanus* (planes)**	Category I	CABI (2017); EU (2015); van der Gaag and Loomans (2014)
***Populus* (poplars)**	Category I	CABI (2017); EU (2015); van der Gaag and Loomans (2014)
***Prunus* (stone fruit)**	Category III	CABI (2017); EU (2015); van der Gaag and Loomans (2014)
***Pyrus* (pears)**		CABI (2017); EU (2015)
***Pyrus bretschneideri* (Chinese white pear)**	Category I	van der Gaag and Loomans (2014)
***Pyrus calleryana* (Callery pear)**	Category III	Van der Gaag and Loomans (2014)
***Quercus* (oak)**	Category III	van der Gaag and Loomans (2014)
Quercus rubra		EU (2015)
Robinia		EU (2015)
***Robinia pesudoacacia* (black locust)**	Category III	CABI (2017); van der Gaag and Loomans (2014)
***Rosa* (roses)**	Category IV	CABI (2017); van der Gaag and Loomans (2014)
***Salix* (willows)**	Category I	CABI (2017); EU (2015); van der Gaag and Loomans (2014)
Sophora	Category IV	CABI (2017); EU (2015); van der Gaag and Loomans (2014)
Sorbus		EU (2015)
***Sorbus aucuparia* (rowan)**	Category I	van der Gaag and Loomans (2014)
Tilia	Category III	EU (2015); van der Gaag and Loomans (2014)
***Toona* (redcedar)**	Category IV	van der Gaag and Loomans (2014)
***Ulmus* (elms)**	Category I	CABI (2017); EU (2015); van der Gaag and Loomans (2014)

Plant stage affected

Vegetative growing stage.

Plant parts affected

Larvae feed within wood, while adults feed on petioles, leaves and bark of young twigs.

Symptoms/signs - description

Whole plant

When beetle densities are high and trees have been attacked for many years, tree death may occur and branches and trees die from the top down (Ric *et al*., 2007). The main stem and large limbs then become either girdled because of the surface feeding on the sapwood or weakened because of the presence of numerous tunnels within the wood. Such trees are susceptible to wind breakage. Crown dieback and early senescence (leaves showing unseasonal yellowing, or drooping in the absence of dry weather) have also been observed by Smith and Wu (2008), and in Germany, Benker and Bögel (2006) observed less foliation on infested maple trees compared to healthy ones. Outbreak levels are worst following several years of drought when hosts are weakened (Gao *et al*., 1997).

Leaves

Adult beetles feed on leaves, twigs, and petioles (leaf stems) (Figure 4). On leaves, they remove the primary and secondary leaf veins, giving rise to characteristic jagged edges along severed leaf tissue (Ric *et al*., 2007). Feeding on the leaves, as well as on the petioles, can cause leaves to be severed from their twigs and may lead to the yellowing of leaves and premature leaf fall during the summer.

Stems

Adults: females chew a hole into the bark and create an **oviposition pit** (largely in the mid-upper canopy in the first year of attack), through which eggs are inserted under the bark. Sometimes, the characteristic marks made by the mandibles are visible around the outer edges of the oviposition pit. Oviposition pits vary in shape from a nearly circular pit (15 mm in diameter) to a narrow slit (about 1 mm in height). **Frothy, white sap** may exude from recently created oviposition slits (FAO, 2009), which can attract insects such as ants, wasps, flies, butterflies and scarab beetles. Typically, oviposition pits, which are a few hours to several weeks old, are reddish in colour. They become darker as the season progresses because they oxidize due to weathering. Oviposition pits created in previous years are dark brown to black. Oviposition pits can be seen at any time of the year on the bole, branches and exposed roots. Seventy five percent of fresh oviposition pits are likely to contain an egg. It should be noted that the diameter of the wood may influence oviposition, with Ding *et al.* (2011) demonstrating that 75% of willow with a diameter > 30 cm were infested in urban areas of Zhengzhou (China), whereas less than 17% of willow with a diameter < 20 cm were infested in the same areas.

Figure 4. Adult *A. glabripennis* feeding damage. © Frank Hérard.

When the adults emerge from the pupal chamber located in the wood they produce circular **exit holes** with a diameter of 6-15 mm (Figures 5 and 6). Ric *et al.* (2007) discovered exit holes throughout the year in Canada on the bole, on branches as small as 3.3 cm in diameter and on exposed roots. Most exit holes are visible for several years, but in some instances, **callus tissue** is produced around the hole. The growth of callus tissue around this type of injury can start soon after adult emergence, especially if it occurs in early summer, and can eventually enclose the exit hole completely. In such cases it is impossible to detect all exit holes present on a tree. Callus tissue may also grow around oviposition pits and feeding galleries.

Figure 5. Close up of *A. glabripennis* exit holes. © Franck Hérard.

Figure 6. *Anoplophora glabripennis* exit holes. © Mateo Maspero.

Larvae: feeding of young larvae on the outer sapwood may lead to the separation of the sapwood from the bark. These areas may appear as sunken or raised bark. Additionally, as a response to the larval feeding, a crack in the bark may become visible. These symptoms appear mostly in the second year following the attack. After more than one year of larval feeding, the bark can also be missing.

Feeding on the surface of the sapwood create depressed **galleries** of various sizes, but these can only be seen when the bark above the feeding gallery has fallen or been removed from the tree. The galleries always occur underneath an oviposition pit and they can still contain live or dead larvae. In the process of creating these galleries, larvae produce solid faecal matter or excrement that is mixed with plant fragments, in this case wood shavings or sawdust, and is called **frass**. This material can be seen protruding through cracks in the bark as it is pushed out of the feeding tunnels by the larvae and is a very important sign for detecting an infestation. Frass occurs on branches, at branch junctions and on the ground at the base of infested trees. The amount of frass is mostly small because the bark is still intact, and rain, snow and wind will make it difficult to detect later in the season or in subsequent years. Callus tissue can also be produced around exposed feeding galleries, but this sign is visible only one to several years after larval feeding has occurred.

After feeding on the outer sapwood, larvae bore **tunnels** toward the heartwood. The entrance of the tunnel has a typical C-shape appearance. Some larvae die in the tunnel and eventually turn dark brown.

Morphology

Pennacchio *et al.* (2012) produced a taxonomic key with detailed morphological pictures for the identification of the larvae of *Anoplophora glabripennis, A. chinensis,* and *Psacothea hilaris,* three species exotic to Europe (See EPPO, 1999; Lingafelter and Hoebeke, 2002; Kimoto and Duthie-Holt, 2006).

Egg: The egg is white when recently laid, and turns to off-white or ivory-white as it matures. It is 5-7 mm long and slightly concave. Eggs are laid singly under the bark and turn yellowish-brown just before hatching. When laid in the summer they hatch in around 10-15 days, depending on the temperature. © Fera Science Ltd.

Larvae: The head has dark brown mouthparts, which are easily seen when looking at the ventral side of the larva. The thoracic and abdominal segments of the larva's body are cream coloured. The first segment of the thorax, located behind the head, is the largest and has a brown sclerotized (i.e., hardened) shield on the dorsal side. The body tapers from that first segment towards the end of the abdomen. The young larva is between 7-20 mm in length and feeds beneath the bark on the sapwood for about 20 days. The mature larva is 30-60 mm in length and tunnels into the wood. © Fera Science Ltd.	
Pupa: The pupa is off-white or ivory-white, 30-37 mm by 11 mm, and is typically found in a pupal chamber located in the wood. © Fera Science Ltd.	
Adults: The body of the adult is jet-black, glossy and may have a bluish tinge. Each wing cover has about 20 white or yellow patches. The antennae have 11 segments that alternate between blue-white and blue-black. The female is 22-36 mm long by 8-12 mm wide, with antennae about 1.2-1.8 times its body length. The male is 19-32 mm long by 6.5-11 mm wide, with antennae about 1.6-2.1 times its body length. © Fera Science Ltd.	

Similarities to other species/diseases/plant damages

Anoplophora glabripennis is very similar to other members of the *Anoplophora* genus, including *Anoplophora chinensis*, but particularly to *Anoplophora coeruleoantennata* and *A. freyi*. All these taxa have the characteristic black integument commonly with scattered white spots on the elytra. The elytral base lacks granulae and has very indistinct microreticulations. The tarsi of fresh specimens of *A. glabripennis* have bright iridescent bluish pubescence, which is less conspicuous in *A. freyi* and *A. coeruleoantennata.* All *A. freyi* have very shiny elytral integuments with a strong iridescent sheen, while in *A. glabripennis* (and *A. coeruleoantennata*) the integument is less shiny (often matte) and less iridescent. *Anoplophora coeruleoantennata* has nearly all antennomeres bluish-purple annulate on at least the basal two-thirds, while on *A. glabripennis*, these annulations are white and restricted to the basal half or lower.

None of our native species resemble *A. glabipennis* or any of the other species *Anoplophora* species. Further information on this can be found in the following document - https://planthealthportal.defra.gov.uk/assets/factsheets/anplophoraLonghornBeetle.pdf

Some non-native insects could be confused with *Anoplophora glabripennis:*

- The adult of *Plectrodera scalator* (Fabricius), known as the cottonwood borer, which occurs in the USA (Wikipedia, 2018) and has white and black markings.
- The adult of *Monochamus scutellatus* (Say), known as the black longhorn, which occurs across North America, is very similar but without white marks (CABI, 2018).
- The larvae of *A. glabripennis* can be distinguished from *Monochamus* spp. chiefly by characters of the pronotum, prosternum and dorsal and ventral ampullae (Cavey, 1998).
- The damage caused by *Anoplophora* beetles could also be confused with native wood-boring insects. The differences between them are described in Malumphy *et al.* (2012).

Detection and inspection methods

Detection on trees and plants

Visual inspection (tree-by-tree) is the primary method for detecting infested trees (Smith and Wu, 2008). Adult beetles usually begin attacking trees near the base of the crown, along both the upper trunk and main branches, though the height varies depending on whether the tree is a species with branches lower down, such as *Populus*, or where branches begin higher up, such as *Acer*.

Certain hosts are preferred by *A. glabripennis*, and Ric *et al.* (2007) suggests focusing surveys or tree inspections on these hosts. *Acer* seems to be infested most often, and

Aesculus, *Betula*, *Populus*, *Salix* and *Ulmus* also seem to be good hosts (Benker and Bögel, 2007; EPPO, 2009a; Hérard *et al.*, 2006; Hu *et al.*, 2009; Schröder *et al.*, 2006).

The following procedure is appropriate when looking for symptoms of infestation:

1) **Inspect the whole plant** for signs of *A. glabripennis* from 1.5 m above ground up (but possible that it could infest lower down) to the middle of the crowns on trees having a clear trunk such as *Betula* and *Acer.* On species with branches along the entire trunk or which have basal suckers, such as *Populus*, inspection should occur from the ground level (Haack *et al*., 2006).

2) Look at **trees and branches** with a diameter of 2.5 cm or more; it is reported that a minimum diameter of 5 cm for egg deposition is required for *A. glabripennis* (Ric *et al.*, 2007).

3) Look **underneath the tree** for signs of frass or prematurely fallen leaves.

4) Look at the leaves for signs of adult feeding.

5) Inspect the trees, branches, and exposed roots for oviposition pits, exit holes, and hollow bark.

6) Look **under the bark** to see larval chambers.

Because the exit holes created by *A. glabripennis* are sealed by cambium tissue in the years following emergence, the number of years since adults emerged from an infested tree can be determined by cutting down an infested tree and examining the wood growth rings. In Italy, for example, Favaro *et al.* (2013) found that 91% (310) of all 339 exit holes were from 2009, whereas about 7% (24) were from 2008. Two holes (0.5%) were from 2007 and 2006, while the oldest exit hole occurred in 2005. Such analysis suggests that *A. glabripennis* occurred in the sampling site from at least 2004, and that the infestation was discovered at least 5 years after the initial introduction.

It should be noted that Smith and Wu (2008) reported that data from USA show that not all trees infested with *A. glabripennis* are detected during surveys. In the best situation, by using a tree climber or bucket trucks in wintertime, about 60-70% of infested trees were detected. Inspections by ground survey crews using binoculars were reported to be approximately 30% effective (Smith and Wu, 2008).

Other detection methods

To improve detection, research has been conducted to test the principle of an acoustic detection system that could be used to detect and discriminate different species of wood-boring larvae, including *A. glabripennis* (Farr and Chesmore, 2007). Mankin *et al.* (2008) has also attempted to characterise the acoustic signatures of different larval stages, and Fleming (2005) has tested the use of ultrasound on solid wood packing materials. However, further development of these methods is necessary before a practical tool is available.

Hoyer-Tomiczek and Sauseng (2009) reported trials by the Austrian Department of Forest Protection of the Federal Research and Training Centre for Forests, Natural Hazards and Landscape, using sniffer dogs to detect *A. glabripennis* in solid wood packaging material (SWPM). The dogs were able to find all stages of development in SWPM in different environments (Hoyer-Tomiczek and Sauseng, 2013). Sniffer dogs are currently only used in Austria.

The plant volatiles S-[beta]-pinene, ethyl acetate, R-[alpha]-pinene and phellandrene, have an attraction effect on male and female adults (Fan *et al.*, 2013). Sex pheromone volatiles from female *A. glabripennis* also attracted more beetles compared with controls when they were field tested between 2006 and 2008 in Ningxia, China (Wickham et al., 2012). However, early studies suggested attractiveness is limited to short distances (Zhang *et al*., 2002; Zhang *et al.*, 2003) and no products are commercially available.

Distribution

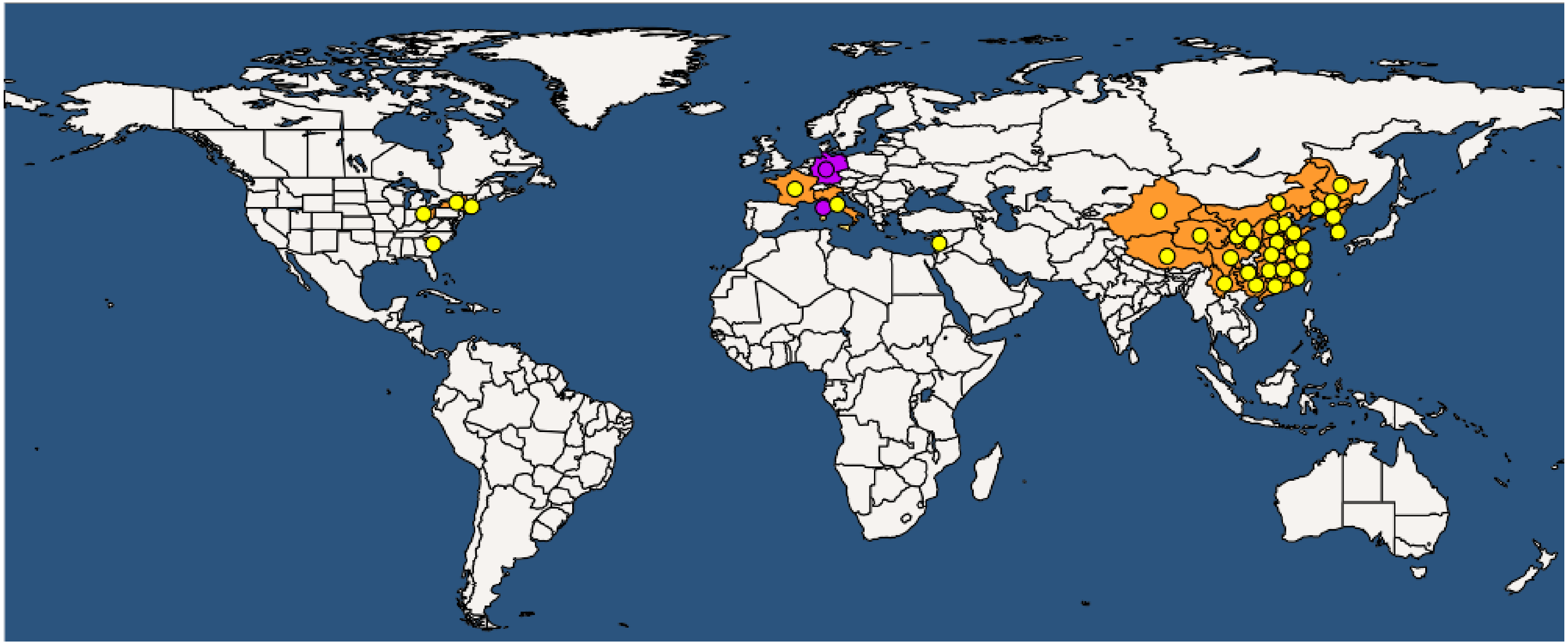

Figure 7. *Anoplophora glabripennis* distribution as of August 2021. (Source: EPPO Global database). The link below provides up to date distribution data.

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

History of introduction/spread

Asia

Anoplophora glabripennis is native to China and Korea. In China, it is widely distributed and since the late 1970's, it has become one of the major tree pests, particularly of poplar (*Populus spp.*) (Gao and Li, 2001; Williams *et al*., 2004). In Korea, *A. glabripennis* remains a relatively uncommon pest, possibly due to differences in habitat (Williams *et al.*, 2004). *Anoplophora glabripennis* is not considered native to Japan, and although there have been findings of specimens in the past (Hu *et al.,* 2009), it is now considered to be eradicated in Japan (Takahashi *et al.*, 2005). A finding in Lebanon in 2018 is currently under eradication (EPPO reporting service, 2018).

North America

USA

Lingafelter and Hoebeke (2002) provide a detailed description of the events following the finding of *A. glabripennis* in the USA. The first finding outside of Asia occurred in 1996 in Brooklyn, New York, when a resident reported seeing large black and white beetles, and reported holes in the Acers lining his street. The identity of the beetles was confirmed by Cornell University and the USDA Animal and Plant health Inspection Service (APHIS) was notified. *Anoplophora glabripennis* is suspected to have arrived in New York City (NYC) sometime between 1982 and 1985 when there was a large re-development of the sewage system in the Brooklyn region of NYC. Each large segment of pipe-work was manufactured in China, and transported enclosed in solid wood packing material, by sea, so that over a number of years a large volume of wood packing material was introduced directly into NYC from China (R. Haack, pers. comm., May 2002).

Following the initial finding, further infestations were found near Amityville on Long Island, and were believed to have resulted from the movement of trees felled for firewood (Haack *et al.*, 1997), in Queens, Manhattan, Stanton and Prall's islands. Eradication of these outbreaks has met with some success given that in May 2013 USDA-APHIS officially announced the eradication of *A. glabripennis* from Manhattan and Stanton Island in New York (NAPPO, 2013), and in 2017, APHIS removed a 28 square mile portion of Queens from the regulated area due to there being no findings for two surveys greater than 4 years apart (NAPPO, 2017a). It was noted that public awareness was crucial for successful eradication of *A. glabripennis* (Cavagna *et al*., 2013). Eradication efforts elsewhere in New York City are ongoing.

In 1998, an outbreak of *A. glabripennis* was identified in an area of Chicago, Illinois (Poland *et al*., 1998). Between 1998 and 2006, numerous quarantine zones were put in place in and around Chicago, and 1,771 trees were removed to eliminate the pest. In March 2008, *A. glabripennis* was declared eradicated following four years of negative surveys. Restoration efforts to replace trees removed because of the beetle have resulted in the planting of 2,682 non-host trees (USDA, 2008).

Outbreaks of *A. glabripennis* have also been found in New Jersey; the first finding being in Hudson country in October 2002, and subsequently in 2004 in Middlesex and Union counties (NAPPO, 2008b). USDA-APHIS declared the eradication of *A. glabripennis* from New Jersey in 2013 following 3 years of negative surveys. To eradicate the beetle, 21,981 trees were removed. Almost a third of these trees have now been replaced by non-host species.

In 2008, in Worcester, Massachusetts, *A. glabripennis* was discovered in a private garden, as well as for the first time in **woodlands**. It had previously only been seen in urban environments of North America. Sampling from two woodland sites showed 32% and 63% of Acers sampled were infested. Of three *Acer* species available, *A. glabripennis* was found more often in *Acer rubrum* than in *A. saccharum* or *A. platanoides*. Sections through trees and examination of tree rings showed that infested trees at one site exhibited slower radial growth and ring width index patterns compared with uninfested trees. Results suggest that if left uncontrolled, *A. glabripennis* could readily disperse into natural forest landscapes and alter the makeup of North America's hardwood forest region (Dodds and Orwig, 2011). Programme activities continue in Worcester County (NAPPO, 2017c).

The latest outbreak was discovered in Clermont County, Ohio, and a quarantine area of 56 square miles was initially demarcated (NAPPO, 2011). Since the first finding, the quarantine area has grown to 62 square miles; most recently, 576 acres of the East Fork Wildlife Area was added due to findings of the beetle in this area (NAPPO, 2017c).

Canada

The first report of *A. glabripennis* infested trees in Canada was made in 2003 when trees showing symptoms were detected in Woodbridge near Toronto in Ontario (NAPPO, 2003). Eradication measures, including the removal of host trees were implemented (EPPO reporting service, 2007). This outbreak was officially eradicated. However, it was subsequently found in September 2013 in Mississauga, Ontario, nearby to the Pearson International Airport (EPPO reporting service, 2015a). All of the infested trees were removed, and , *A. glabripennis* has not been detected since (EPPO reporting service, 2015a). *Anoplophora glabripennis* is not thought to have spread into Canada from the New York / New Jersey outbreaks in the USA, but instead is thought to be the result of new and separate entry events. This outbreak has now been declared eradicated (EPPO reporting service, 2020a).

Europe

Austria

Infestation symptoms were first detected in Europe in November 2000, in Braunau am Inn, a small Austrian city near the German border. *Anoplophora glabripennis* was then confirmed in July 2001, following the first finding of an emerged beetle (EPPO reporting service, 2001; Krehan, 2008). As in the USA, the pest was probably introduced on packing material from Asia, with the infestation being close to a market place where various imported products from China were sold (EPPO reporting service, 2002). In response to the outbreak, trees were cut down and the number of infested trees found declined from 2001 to 2006. However, two new sites of infestation were found in 2007 and another in 2008 in Braunau. The outbreak was eventually declared eradicated in 2013 (EPPO reporting service, 2013g). In 2012, three further trees were found to be infested in Geinberg, which were likely to have been introduced from wood packaging material for stone imports from China. Since 2012, there have been no further findings in Geinberg and the beetle is considered to have been eradicated (EPPO reporting service, 2017a). A further outbreak in Gallspach, was declared in 2013 (EPPO reporting service, 2017a), but this has since been eradicated (EPPO reporting service, 2020b).

France

The first outbreak in France was reported in May 2003 (Cocquempot *et al.*, 2003) in the city of Gien (Loiret). A second infestation was discovered in 2004 in the village of Saint-Anne-sur-Brivet (Loire-Atlantique) (EPPO reporting service, 2004a). Following eradication efforts, surveys in 2007 identified 20 trees with symptoms of infestation but no adults in Gien, and no trees with symptoms or adult beetles in Saint-Anne-Sur-Brivet (EPPO reporting service, 2008b). Eradication was considered feasible in both cases. However, the pest was reported at two new locations in 2008 – Strasbourg (Bas-Rhin) and Velars-sur-Ouche (Côte d'Or) (EPPO reporting service, 2010a), in 2013, in Haute-Corse (Corse region) in private gardens in the municipality of Furiani (EPPO reporting service, 2013b), and in 2017, in the municipality of Divonne-les-Bain (EPPO reporting service, 2017b). The outbreaks in Strasbourg and Saint-Anne-Sur_Brivet have now been declared eradicated (EPPO reporting service, 2021e), with the other outbreak sites remaining under eradication measures.

Germany

The first finding of an infestation in Germany occurred in 2004, following the discovery of exit holes and living larvae in trees in Neukirchen, Bayern. The larvae were of various instars, indicating that oviposition had taken place in two different years before the outbreak was discovered (EPPO reporting service, 2004b). In 2005, the pest was also found at Bornheim near Bonn, Nordrhein-Westfalen. In both outbreaks, infested trees were located close to an importer of stone from China and it is believed that the pest was introduced with wooden packaging material. Eradication measures have been taken at both locations (EPPO reporting service, 2008c). In 2009, a second infestation site was discovered close to Bornheim but outside the buffer zone already in place. It is not known if this is a new introduction or due to dispersal from the original site. Successful eradication was declared at Neukirchen in 2016 (EPPO reporting service, 2016d). Further findings were made in Grenzach-Wyhlen in 2011 and in October 2012, infested trees were found near Münich (Bayern) (EPPO reporting service, 2013c). The beetle was also detected in Neubiberg, in Ziemetshausen near Augsburg, in Bayern (Bavaria) in 2014 (EPPO reporting service, 2014a), and in Kelheim and Murnau (Bayern) and Hildrizhausen in 2016 (EPPO reporting service, 2016a, 2017c). *Anoplophora glabripennis* was also found for the first time in Saxony-Anhalt, in Magdeburg, in a single *Aesculus* tree in 2014 (EPPO reporting service, 2014a). A new outbreak was detected in 2019 in Miesbach (Bavaria) (EPPO reporting service, 2021d). The outbreaks in Grenzach-Wyhlen and Hildrizhausen (Baden Württemberg), Feldkirchen, Neubiberg, Kelheim and Murnau (Bavaria) have now been eradicated (EPPO reporting service, 2021d) with the other sites remaining under eradication measures.

Italy

In 2007, a survey for the related pest *Anoplophora chinensis* in Corbetta in the province of Milano, Lombardia, Italy revealed the presence of *A. glabripennis* in a private garden (Maspero *et al.*, 2007). All infested trees were destroyed, along with potential hosts in a 500 m radius (EPPO, reporting service 2009c). In June 2009, a second outbreak was discovered, again in a private garden, at Cornuda, province of Treviso, Veneto (EPPO reporting service, 2010b). In 2010, the NPPO of Italy reported another outbreak in the province of Treviso - a group of infested trees in the municipality of Maser (EPPO reporting service 2010b). All infested trees are being destroyed. In 2013, a further outbreak was detected in the municipality of Grottazzolina in the Marche region, following the report of suspicious symptoms on a maple tree (EPPO reporting service, 2013d). Eradication continues in some regions of Italy, although the outbreaks in Veneto have since been declared eradicated (EPPO reporting service, 2020e).

Switzerland

The beetle was first recorded from a photograph taken by the owner of a private garden in Brünisried (Canton of Fribourg) in September 2011 (EPPO reporting service, 2011a). The presence of beetles in the area was later confirmed following a visit by the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL). It is suspected that the beetles arrived with stone imports from China, as stones had been used on a road nearby. Later in 2011, dead beetles were identified from a construction site near Salenstein (Canton of Thurgau) and were also traced back to a consignment of stones from China (EPPO reporting service, 2011b). The following year, 30 *Acer pseudoplatanus* trees and one *Salix caprea* were found to be infested with *A. glabripennis* in the municipality of Winterthur, canton of Zürich (EPPO reporting service, 2013e). These trees, as well as other potentially infested trees, were destroyed, and a survey was carried out. No findings have been found since 2013 and the outbreak was declared eradicated at the end of 2016 (EPPO reporting service, 2017f). There were also findings in the municipality of Marly (Canton of Fribourg) in 2014 and the municipality of Berikon (Canton of Aargau) in 2015. All outbreaks have now been declared eradicated by the NPPO of Switzerland and the pest status is absent, pest eradicated (EPPO reporting service, 2021b).

United Kingdom

An outbreak of *A. glabripennis* was confirmed in the UK from Kent in March 2012. The outbreak was close to a building / landscaping company that had imported stone from China. An adult beetle had been discovered in 2009, but no trees had been found infested at that time. Eradication was implemented to inhibit the chance of pest spread. By July 2012, 67 infested trees had been detected and over 250 live larvae recovered from such trees. Over 2,000 trees were cut down as part of eradication efforts. This included all trees showing signs of infestation, and the main hosts within the infestation zone. Surveys for the beetle have been carried out annually at the outbreak site, but no beetles have been found since 2012. The beetle was declared eradicated in 2019 (EPPO reporting service, 2021c).

Russia

In 2014, a single male *A. glabripennis* was discovered in the Primorsky Krai territory (EPPO reporting service, 2017e; Shamaev, 2016). It has since been eradicated from the region (EPPO reporting service, 2020c).

Finland

In 2015, *A. glabripennis* was discovered in a number of trees nearby to a stone import company in Vantaa city (EPPO reporting service, 2015b, 2016e). Following surveys, 132 suspicious trees were identified and cut down, and beetles were found within wood packaging material at the stone importer. The infested area covers around 10 ha and all host trees within the area were cut down. A buffer zone with a 2 km radius was also demarcated, from which there were restrictions on the movement of wood material unless treated. The pest was declared eradicated in 2020 (EPPO reporting service, 2021b).

Montenegro

Anoplophora glabripennis was discovered on a willow tree in the municipality of Budva in 2015. The tree was destroyed and the outbreak was declared eradicated in 2020(EPPO reporting service, 2017d and 2020d).

European countries where *A. glabripennis* does not occur

Croatia conducts two annual visual inspections of forests at specific and predetermined localities. *Anoplophora glabripennis* and *A. chinensis* are amongst the target species that authorities are on the lookout for (Pernek, 2012) but so far neither have been found (Pernek, 2012).

Cyprus, Estonia, Hungary, Lithuania, Malta, Portugal, Slovenia, Sweden and Turkey have also conducted surveys for *A. glabripennis*. The status of *A. glabripennis* in these countries is “absent, confirmed by survey” (EPPO, 2017).

Phytosanitary status

Anoplophora glabripennis is a GB quarantine pest (Schedule 1), which means that it is prohibited from being introduced into, or spread within GB. It is also present on several other phytosanitary lists.

Table 1. Global phytosanitary categorisation of *A. glabripennisi*.

Country/NPPO/RPPO	List	Year of addition
	AMERICA	
Canada	Quarantine pest	2000
USA	Quarantine pest	1998
	ASIA	
Kazakhstan	A1 list	2009
	EUROPE	
Moldova	A1 list	2006
Russia	A1 list	2014
Turkey	A1 list	2007
Ukraine	A1 list	2010
	RPPO/EU	
EAEU	A1 list	2016
EPPO	A1 list	1999
EU	Annex I/A1	2004
EU	Emergency measures	2015

Figure 8. Outbreaks of *A. glabripennis* in Europe up to 2016. Red = current outbreaks, orange = surveillance zone, green = declared eradication.

Means of movement and dispersal into the UK

Natural dispersal

To locate suitable host trees, adult beetles are capable of flying several hundred meters or more in a single flight. Flight mill experiments have shown, for example, that adults can fly an average of 2,272 m within a 24 h period, and a maximum distance of 13,667 m (Lopez *et al.*, 2017). Over the year, population dispersal distance measured by Wen *et al*. (1998) was 106 m, and this dispersal was positively correlated with wind velocity and temperature. In Beijing poplar groves, *A. glabripennis* spread at less than 300 m per year (Cavey 2000 cited by Pan, 2005), and a mean dispersal distance of 266 m has been recorded using the mark–release–recapture method (Smith *et al*., 2001). Further mark–release–recapture studies demonstrated that, although 72% of beetles were recaptured within 300 m of release points, some beetles were recaptured up to 2,600 m away (Smith *et al*., 2004). Dispersal potential within the course of a season for males was 2,394 m and 2,644 m for gravid females. Nevertheless, 98% of the marked beetles were recaptured within 920 m from the release point and adults fly to nearby host trees at a rate of 34% per day (Smith *et al*., 2004). Thus, whilst adults can disperse up to 3 km during their life span, most remain on or close to the tree where they emerged (Bancroft and Smith, 2005; Smith *et al.*, 2001, Smith *et al.*, 2004). In these studies, beetle dispersal from release trees was positively associated with the abundance of beetles at the release tree and smaller female beetles moved greater distances and were more attracted to taller trees (Bancroft and Smith, 2005). Recognizing that a higher beetle density encourages dispersal (Bancroft and Smith, 2005), it is likely that outbreaks will tend to remain localized until some threshold density is reached. Sawyer (2007) also showed that beetles remained nearby to where they emerged when host trees were densely planted nearby and resources had yet to be overexploited, respectively. In another study, Li *et al*. (2010) found population dispersal was affected mainly by the wind direction, with most dispersal occurring upwind (i.e. in the opposite direction to prevailing winds). Generally, beetle movement shows a significant response to beetle density, weather conditions, beetle size, and tree size, in that order (Bancroft and Smith, 2005).

Movement in trade

Trade with solid wood packaging material is the most important pathway for long distance dispersal of *A. glabripennis*. Haack *et al.* (2010) compared 219 interceptions of *A. glabripennis* and *A. chinensis* from 18 countries from 1980 to 2008 and both *A. glabripennis* and *A. chinensis* were intercepted in wood packaging material (WPM) associated with imports such as steel, ironware, tiles, and quarry products, as well as in live woody plants such as bonsai and nursery stock. Where species-level identifications were made (75% of 219 interceptions), most *Anoplophora* interceptions on WPM were *A. glabripennis* (96%), whereas most *Anoplophora* interceptions on live plants (i.e., bonsai and plants for planting) were *A. chinensis* (99%).

Between 1999 and 2013, there were 306 interceptions of longhorn beetles on wood packaging material that were reported on the EU’s Europhyt database. When the beetles were identified to genus or species level (181 interceptions), almost half the interceptions related to either *Anoplophora glabripennis* (57 interceptions) or *Anoplophora* sp. (22). The *Anoplophora* sp. are very likely to have been *A. glabripennis* given that there is only one record of another *Anoplophora* sp. being associated with wood packaging material in Europe: an interception of *A. chinensis* in 2007.

Control

Cultural controls and sanitary methods

Removal and destruction of infested and symptomatic trees has been used as a quarantine measure in North American, Asian and European outbreaks (Haack *et al*., 1997; Hoyer-Tomiczek and Cech, 2008; Takahashi, 2005). There is a risk of infested trees being overlooked due to the difficulties of detecting the pest when inside a host (30%

efficacy for ground surveys, 60-75% for tree climbing; Smith and Wu, 2008), and therefore the precautionary removal of potential hosts near to infested trees is considered necessary. Chipping wood from infested trees without incineration of the resulting wood chips has been shown to be an effective method for destroying wood containing pests such as *A. glabripennis* (Wang *et al*., 2000).

To aid surveys, pheromone trapping has also been studied. Nehme *et al.* (2010) trialled the use of two pheromones produced by males (4-(*n*-heptyloxy) butan-1-ol and 4-(n-heptyloxy) butanal), together with a mixture of plant volatiles (linalool, linalool oxide, *cis*-3-hexen-1-ol, *trans*-pinocarveol, and *trans*-caryophyllene), and showed the bait increased capture rates of females. Nehme *et al.* (2010) also identified Intercept panel traps to be the most effective and practical traps for use with this bait. Meng *et al.* (2014) and Nehme *et al.* (2014) likewise found traps baited with pheromones to be more effective for catching *A. glabripennis*.

In trials, timber production in pure stands of *P. alba* var*. pyramidalis* was significantly lower than from mixed stands consisting of *P. alba var pyramidalis* and *Acer negundo* (Wang *et al*., 2006). Wen *et al.* (2006) also studied timber production from stands of mixed tree species and found a variety of species mixtures that could sustain losses from *A. glabripennis* and still meet timber production needs. Planting *Melia azedarach* and *Acer negundo* amongst poplar has been shown to reduce pest damage in *Populus* by 60-70% (Sun *et al*., 1990). However, diversity has not shown to improve the resilience of tree systems in all cases; Berland and Elliot (2014) found that more diverse systems in Minnesota were actually highly susceptible to *A. glabripennis*.

Resistance

Populations of *A. glabripennis* from different locations have been shown to have different host preferences. These preferences also seem to vary slightly under different environmental conditions. Thus, effects of host quality and host species should be taken into account when management decisions are made (Keena, 2002) and further research into other hosts which may be exposed to the beetle in new infestation areas should be carried out.

Pan *et al.* (2015) also studied the secondary metabolite, gutta-percha, of the tree, *Eucommia ulmoides*. They found that *A. glabripennis* fed significantly less when given a diet containing greater than 6% gutta-percha, suggesting gutta-percha could be used as an antifeedant.

Biological control

Screening for entomopathogenic nematodes has been carried out (Fallon *et al*., 2004; Solter *et al*., 2001), including a study by Li *et al.* (2011), which showed *Heterorhabditis* sp ZH to be an effective strain causing almost 95% mortality in adults and 100% mortality in larvae of *A. glabripennis*. However, no nematodes are commercially available for use against the beetle.

In north-west China, Wei and Niu (2011) showed that the parasitoid beetle, *Dastarcus helophoroides*, reduced the number of holes per tree from an average of 4.6 to 0.9 over 3 years in a parasitoid release site, whilst the average number of holes per tree at a control site did not significantly change (7.4 to 7.7). It was concluded that in China, *D. helophoroides* could effectively control *A. glabripennis* and has potential as a natural enemy.

Researchers in Italy conducting surveys for possible European natural enemies of *A. glabripennis* found that the hymenopteran ectoparasitoids, *Spathius erythrocephalus* and *Trigonoderus princeps* are the parasitoids most frequently observed in *Anoplophora* spp. in Italy and although both possess attributes of good biological control agents, they are not being considered for release against *Anoplophora* spp. because of their polyphagy (Herard *et al*., 2013). A similar survey was conducted in North America, where 5 parasitic hymenopteran species were identified as being able to parasitise *A. glabripennis* larvae and produce viable offspring (Duan *et al.*, 2016). These included *Ontsira mellipes*, *Rhoptrocentrus piceus*, *Heterospillus* sp., *Spathius laflammei* and *Atanycolus* sp. *Ontsira mellipes* and *R. piceus* showed the most promise, and *O. mellipes* has since been studied further. Duan *et al.* (2016) and Golec *et al.* (2016) showed *O. mellipes* to have an average parasitism rate in red maple sticks of 51 and 21.4%, respectively, and Duan *et al.* (2016) also demonstrated parasitism of 69% in red maple bolts. In some parts of the US, *O. mellipes* may be able to complete between 1.2 and 3.7 generations on *A. glabripennis* (Golec *et al.*, 2017).

The use of entompathogenic fungal bands, such as with *Metarhizium brunneum*, that could be wrapped around trees to inoculate adults as they walk over them has been studied by Ugine *et al*. (2013 a, b). The researchers found fungal bands can deliver lethal conidial doses to adult *A. glabripennis*, with higher doses being transferred to adults, resulting in shorter adult survival times, when bands are made using “shaggy” textured material, rather than a flat material. Interestingly, adults that pick up conidia after walking across these bands are also able to transfer the conidia to other adults by contact e.g. when mating. When males were paired with females ≤ 24 hours after exposure, all females died (Ugine *et al.*, 2014). While the effect decreased slightly after 48 hours, likely as a result of physical attachment of the conidia to males, and the loss of unattached conidia, 81.3% of females still died (Ugine *et al.*, 2014). The effect was less pronounced when females were first exposed (only 56.3% of males died 24 hours after female exposure) and may be due to the positioning of males above and behind females during mate guarding, resulting in less contact with parts of the females that have picked up conidia (Ugine *et al.*, 2014). Lab tests using both imidacloprid and *Metarhizium brunneum* have also shown synergistic effects of dual treatment, with infected beetles surviving for less time than individually treated beetles (Russell *et al*., 2010). Because fungal bands can be difficult to apply high up in a tree and do not cover a large surface area, a spray formulation of *M. brunneum* has also been looked into. A spray combining the microsclerotia of *M. brunneum* and hydromulch (moist wheat straw and glue) was shown to reduce the survival of *A. glabripennis* under laboratory conditions (Goble *et al.*, 2015, 2016a) and has shown potential when used under field conditions (Goble *et al.*, 2016b).

Wang *et al.* (2010) also found that *Metarhizium anisopliae* Sorokin MS01 reduced feeding, fecundity, egg hatching rate, and the survival of offspring when it infected adults of *A. glabripennis*. Likewise, Higuchi *et al.* (1997) found that *Beauveria brongniartii* was highly virulent against cerambycids in Japan, including *A. glabripennis*. North American isolates of *B. brongniartii* also showed some effect against *A. glabripennis*, but the isolates were shown to be inferior to *M. brunneum* and *Beauveria asiatica* in a study by Goble *et al.* (2014). The use of *Bacillus thuringiensis* has also not shown to be effective (D'Amico *et al*., 2004).

No parasitic mites have been collected from *A. glabripennis* in China and the USA (Husband and Husband, 2011).

Field monitoring/economic threshold levels

Luo *et al*. (1999) studied *A. glabripennis* impacts in mixed shelterbelts consisting of *P. opera* and *P. alba* var. *pyramidalis* in a ratio of 1:3, that were between 8 and 10 years old, in Qingtongxia City, Ningxia. They concluded that when there are more than 4.8 exit holes per tree, active management to control *A. glabripennis* damage is justified. In contrast, there is no information concerning damage thresholds and very little about damage by *A. glabripennis* in commercial fruit trees.

Chemical control

Currently, soil and tree trunk injection with imidacloprid is used as a precautionary treatment for uninfested trees, as is the case in New York (Lance, 2003). Adult reproductive output and survival were significantly reduced when beetles were fed on twig bark or leaves from trees treated with imidacloprid. However, results from trials vary widely, with many twig samples from treated trees having no detectable imidacloprid and little effect on the beetles. When twigs with > 1 ppm imidacloprid in the bark were fed to mated beetles, the number of larvae produced was reduced by 94%. When given a choice of control twigs and twigs from injected trees, beetles did not show a strong preference (Ugine *et al.*, 2012). The 21 d LC50 value for adult beetles feeding on twig bark from imidacloprid-injected trees was 1.3 ppm. Adult females that did not die from imidacloprid exposure laid 23-38% fewer viable eggs, suggesting there is also a sub-lethal effect of imidacloprid (Ugine *et al.*, 2011). There was also an upsurge in *Tetranychus schoenei* (spider mite) populations following treatment, as a result of its non-target effects (Szczepaniec *et al.*, 2011).

Lambda cyhalothrin could also provide an alternative to imidacloprid for the treatment of trees. The LD50 and LD90 of *A. glabripennis* adults following exposure to the chemical was 0.13639 and 0.78461 mu g/beetle, respectively (Wu and Smith, 2015). When the beetle was exposed to different concentrations of the chemical formulation (150, 300, 450 and 600 mg/litre) following the application of the formulation to the environment 10, 20, 45, 69 and 90 days previously, the beetle experienced 100% mortality, except after 90 d for concentrations of 150 and 300 mg/litre (Wu and Smith, 2015). A higher concentration of 1200 mg/litre also gave 100% mortality 158 days after application (Wu and Smith, 2015).

Following the ban of methyl bromide, the only treatment options available against *A. glabripennis* for wood packaging are a heat treatment or sulfuryl fluoride (ISPM 15). Hydrogen cyanide also has potential, however; Stejskal *et al.* (2014) demonstrated that the fumigant could kill *A. glabripennis* in as little as 1 hour.

Impacts

Economic impact

Impact in China

Anoplophora glabripennis is one of 107 species of longhorn beetle species that feed on poplar trees in China. At least 11 of these beetle species cause large scale economic injury (Li and Wu, 2003), and *Anoplophora glabripennis*, along with *A. chinensis*, is considered to be one of the most serious forest pests in Zhejiang Province, China (Zhang *et al*., 2012), and is estimated to cause losses of around US $1.5 billion per year.

As an indigenous species, *A. glabripennis* was not considered a serious pest in China before the 1980s. There were only 5 reports concerning *A. glabripennis* and its control during the 1960s and 1970s (Gao and Li, 2001). However, in the 1980s, there were over 200 papers published on various aspects of the biology and pest status of *A. glabripennis* in China (Gao and Li, 2001). The change in pest status was due to the wide spread planting of susceptible poplar and willow, some of which came from Europe and America, and were planted in reforestation projects across China, such as the sanbei (three-north) forest belt project, which covered the north east, north and north-west of China. The project began in the late 1970s and aimed to stop desertification and the expansion of the Gobi desert (Taketani, 2001). Within the Sanbei region, 20 million ha of plantation were established with *Populus* and *Salix* dominating. *Ulmus* (elms) and *Acer* (maples) are also attacked (Gao and Li, 2001). Britton and Sun (2002) reported that unpublished Chinese State Forestry statistics estimated that one third of trees planted in the Sanbei belt project had been killed by *A. glabripennis*. The key provinces where most *A. glabripennis* damage occurred was in Shaanxi, Gansu, Shanxi, Ningxia, and Inner Mongolia with *A. glabripennis* occupying approximately 330,000 ha in 1994 (Luo *et al*., 2003). Hoebeke (2007) also reported Chinese media accounts that claimed *A. glabripennis* had killed 142 million trees in one province over a six year period.

In addition to the loss of trees, the standard of recoverable timber is also reduced. Timber standards in China divide wood into quality ranks according to the amount of bore holes in each 1 m length of wood. The premium 1st rank wood has no holes. The 2nd rank wood has 1 to 5 holes per metre and the 3rd rank has more than 5 holes per metre. The value of timber decreases by 25% from 1st to 2nd rank, and the difference in value between the 1st and 3rd rank wood is 46% (Gao *et al*., 1993). From dissecting wood from 16 year old *P.* x *dokuanensis* and *P.* x *simopyramdalis*, Gao *et al*. (1993) found that *A. glabripennis* could degrade 89% of the wood into 3rd grade. In some cases, the wood cannot be used at all; in Ningxia, one of the five most affected provinces, the wood from 50 million infested trees that were felled between winter 1991 and summer 1993 could not be sold. It was all burned causing estimated losses of US$ 37 million (Gao and Li, 2001; Hoebeke, 2007).

Impact in South Korea

Anoplophora glabripennis is relatively rare in South Korea (Williams *et al*., 2004) and is only reported from *Acer* species, particularly *Acer mono* (*Acer pictum* subsp. *mono*) and *A. truncatum* in natural forest stands. In surveys during 2000 and 2001, less than 10% of the trees at two sites in South Korea exhibited evidence of beetle damage, and few adult beetles were observed (Williams *et al.*, 2004). Like China, South Korea had undertaken large reforestation projects which have included growing *Populus* spp. susceptible to *A. glabripennis*. Although damage has not been reported from reforested areas, there is potential for *A. glabripennis* to spread and cause harm in South Korea (Haack *et al*., 2010).

Impact in Japan

When an outbreak of *A. glabripennis* was discovered in *Ulmus parvifolia* (Chinese elms) trees in the streets of Yokohama city, Japan, in July 2002, damage to infested trees was mixed. Some were reported as lightly damaged and others as heavily damaged (Takahashi, 2005). Destruction of the heavily damaged trees, and chemical treatment of lightly damaged trees resulted in successful eradication (Takahashi, 2005).

Impact in Europe

Williams *et al.* (2010) estimated the economic impact of invasive species in Great Britain and used *A. glabripennis* as a case study example. Unfortunately, very crude assumptions were made to estimate potential impacts. For example, it was assumed outbreaks would occur in hardwood forests, each single infested tree would be detected, and all trees within a radius of 500 m of an infested tree would be felled. The trees in this area (78.5ha) were assumed to yield 155 m^3 ha^{-1} of timber worth £28.5 m^{-3}. Felling 78.5 ha of forest would cost around £347,000 in lost timber value. It was then assumed a widespread infestation would occupy 25% of the hardwood forests of England and result in loss in timber worth around £844 million, were it to be felled. The cost of eradication from other habitats, such as parks and gardens or hedgerows (where real outbreaks actually occur) was not estimated. By comparing the relative output of US and UK hardwood forestry, Williams *et al.* (2010) suggested an alternative impact of *A. glabripennis* to the UK hardwood industry would be approximately £435 million. This was based on reducing an estimated potential impact on US hardwoods of $138 billion (Meyer 1998) in proportion to the output of UK hardwoods.

Up until 2008, total costs estimated for eradication attempts in Austria, France and Germany were €464,000, €55,000, and €65,000, respectively (Haack *et al.*, 2010), while in the first year of eradication in the municipality of Cornuda (Italy), in 2009, costs of tree removal, surveys and scientific advice were estimated to be €48,000 (Faccoli and Gatto, 2015). Faccoli and Gatto (2015) also estimated that the average ornamental value of infested and cut trees in the municipality of Cornuda was €854, and the total ornamental value of infested trees was €313, 514.

Impact in the USA

Anoplophora glabripennis is perceived to pose a very significant threat to hardwood trees in the USA and Canada. Following its finding in New York City in 1996, action has been taken to contain and eradicate it. It was reported that only two years after action began, the cost of the official campaign to suppress the 1996 infestation in New York State was more than US$ 4 million (USDA, 1998). This figure grew such that from 1997 to 2006, APHIS and the states of New York, Illinois and New Jersey and local governments spent more than $800 million on *A. glabripennis* eradication measures (Smith and Wu 2008), and as of 2008, the costs of eradication were estimated to be US$ 373 million (Haack *et al.*, 2010). Nevertheless, such spending has been justified given that the value of tree resources at risk in New York City alone is around US $2,250 million (US$ 2.25 billion) (Nowak *et al.*, 2001). Thousands of infested urban trees have been removed in efforts to eradicate *A. glabripennis* from New York State and Illinois. Replacement trees, including oaks, have been replanted with tree species thought not to be hosts for the beetle. However, Morewood *et al*. (2005) showed that northern red oak, *Quercus rubra* could be an *A. glabripennis* host. Thus, trees planted to prevent population build up could act to sustain *A. glabripennis* impacts in future. USDA APHIS considers *A. glabripennis* to have "the potential to cause more damage than Dutch elm disease, chestnut blight and gypsy moth combined". Several workers have modelled the regions where climate is suitable for potential establishment e.g. Peterson (2004) identified where impacts could occur in North America. Nowak *et al*. (2001) studied potential impacts to urban trees in nine large US cities and estimated that *A. glabripennis* could destroy in excess of 10 million trees identified as preferred hosts, representing between 12% (in Oakland, CA) and 61 % (in Chicago, IL) of trees in the nine cities. The value of the preferred hosts in each city ranged from US$ 72 million (Jersey City, NJ) to US$ 2, 509 million (Chicago). Nowak *et al*. (2001) estimated the maximum potential impact across all nine cities to be a loss of 1.2 billion trees, representing 30% tree mortality and 35% loss of canopy cover, combining to have a value of US$ 669,000 million. In addition to the loss of urban greenery, there would be losses in the timber industry and knock on effects to furniture making, leading to even greater economic impacts. Sugar maple syrup industries would also be at risk (Smith and Wu 2008).

Impact in Canada

Eradication costs, as of 2008, have been estimated at CAN$ 23.5 million (Haack *et al.*, 2010).

Environmental impact

Urban trees are responsible for several ecosystem services, including microclimate amelioration (mainly evapotranspiration-cooling effects), carbon dioxide sequestration, oxygen generation, and the removal of gaseous and particulate pollutants (Jim and Chen, 2009). Such benefits are lost if trees are killed or cut down and remain lost until equivalent sized trees can replace them.

Loss of trees in more natural environments can give rise to soil instability and increase the risk of erosion and fire. In some parts of China, the impact of *A. glabripennis* on the three principal poplar species, *P. dakuanensis*, *P. x canadensis* and *P. nigra* var *italica*, resulted in large losses of trees (Gao *et al.*, 1993) undermining the aim of official reforestation programmes. However, mixed woodland planting shows less damage from *A. glabripennis* and damage decreases as tree diversity increases (Li *et al*., 2005). There is no indication that *A. glabripennis* is a pest of natural forests in China (Smith *et al*., 2009) or Korea (Williams *et al*., 2004). However, if *A. glabripennis* does spread out of its current urban environment into natural forests in North America it has the potential to seriously alter the ecological diversity of the natural forests with additional impacts on wetlands. The potential impact to forests is the loss of 71 billion trees valued at over $2 trillion dollars (GAO, 2006). The outbreak of *A. glabripennis* in wooded areas of Worcester (MA, USA) indicates that *A. glabripennis* can indeed succeed in areas beyond the urban environment. *Anoplophora glabripennis* may have been present in Worcester for around 10 or so years before being detected during which time almost 20,000 trees have been infested. Some trees have been found with more than 300 adult emergence holes, signifying heavy infestation. Such damage can kill trees and it appears likely that without intervention *A. glabripennis* could cause serious tree mortality in susceptible forestry and woodland trees.

Social impact

The loss of trees resulting from *A. glabripennis* infestation would negatively affect recreational and amenity sites (Jim and Chen, 2009), and could potentially reduce tourism, such as visits to New England, USA, to see the famous autumn colours (Smith and Wu, 2008).

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