Forest Research

Briefing Note

Threats to European trees from the emerald ash borer and bronze birch borer

Hugh Evans, Mariella Marzano, Dave Williams, Gernot Hoch and Antoon Loomans

Introduction

Globally, there are more than 3,200 species in the beetle genus *Agrilus* (Jendek and Polakova, 2014). Among these, several species have occasional, or sometimes frequent, pest status, particularly in invaded ranges. Notably, the emerald ash borer (EAB), *Agrilus planipennis*, which originates from South-east Asia, has become a serious killer of ash trees in North America and in the European part of Russia, with a recent expansion into Ukraine. Recognising the devastation caused to ash trees since its arrival as an invasive pest in these locations in the 1990s, the Euphresco project PREPSYS was set up in 2016 and ran for three years to September 2019. Among the many outputs from the project, an international conference was held in Vienna in October 2018, leading to a special edition of *Forestry: An International Journal of Forest Research*, containing 14 papers, in April 2020. Many international experts on EAB and its close relative the bronze birch borer (BBB), *Agrilus anxius*, contributed to the conference and subsequent publications. This illustrated document summarises the biology and main findings on the two beetle species, though research continues on both species, especially EAB.

Biology and life cycles of EAB and BBB

There are great similarities in the biology and life cycles of EAB and BBB. Both beetle species have a one- or two-year life cycle depending on climate. This is illustrated in Figure 1 for EAB reproduced from Villari *et al.* (2016).

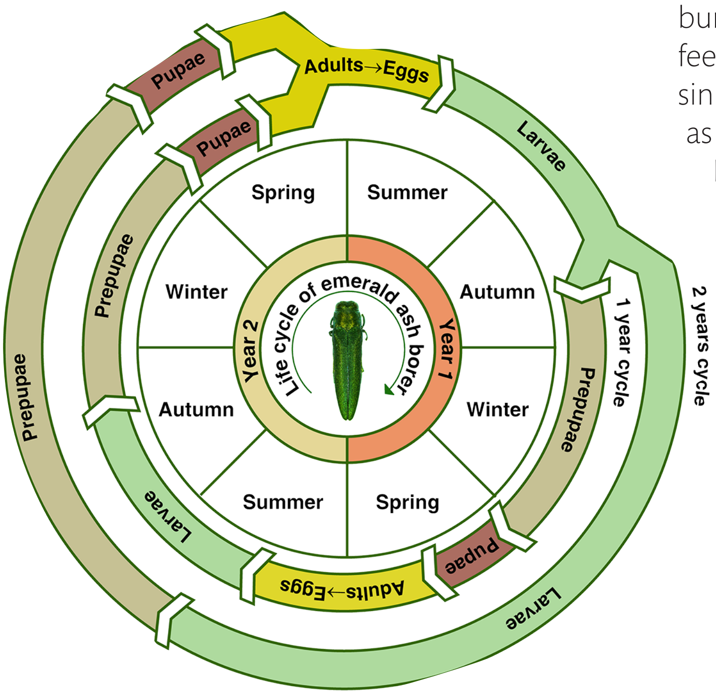
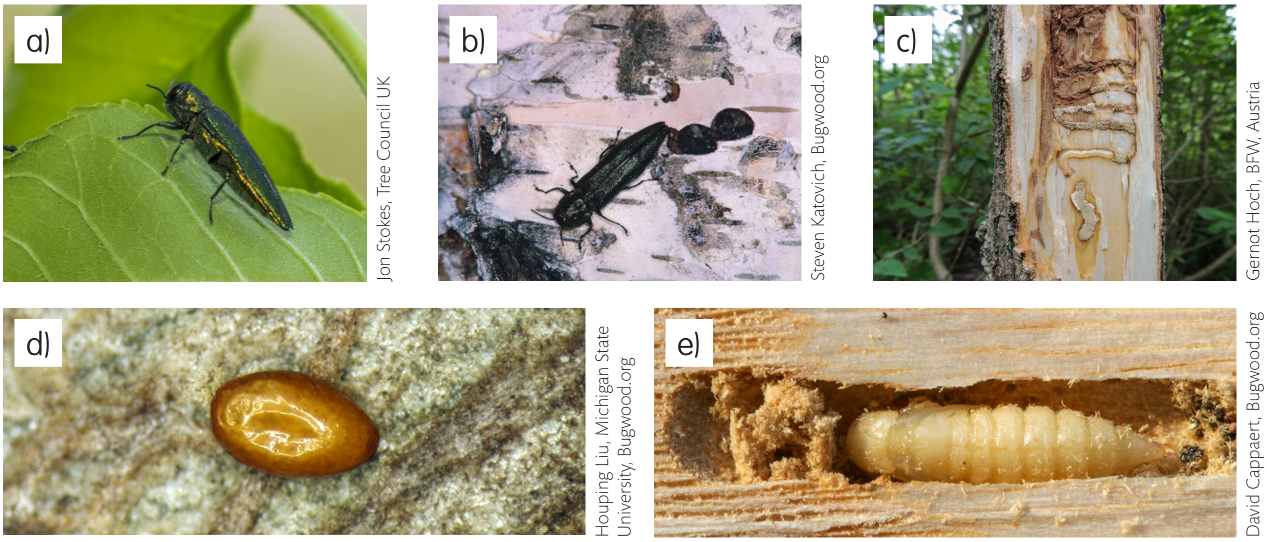


Figure 1 Illustration of the EAB one- and two-year lifecycles.

Adults of both species feed on the foliage of host trees, with females living for up to 23 days, and males slightly less. Eggs (up to 90 per female) are laid in bark crevices, singly or in small clusters and hatch in 7 to 10 days. Larvae burrow through the outer bark and begin feeding in the phloem beneath, producing sinuous tunnels that get progressively larger as the larvae develop through four stages. Feeding tunnels can be up to 30 cm long with final-stage larvae up to 32 mm in length. Depending on temperature and precisely when the eggs are laid, larvae may overwinter as prepupae (one-year cycle) or remain as larvae and continue feeding in spring and summer (two-year cycle). In the following spring, pupation followed by adult emergence or continuing larval development may take place.

[Figure 1] Villari, C., Herms, D.A., Whitehill, J.G.A., Cipollini, D. and Bonello, P. (2016), Progress and gaps in understanding mechanisms of ash tree resistance to emerald ash borer, a model for wood-boring insects that kill angiosperms. New Phytol, 209: 63-79. https://doi.org/10.1111/nph.13604



Various life stages of the beetles: a) adult emerald ash borer; b) adult bronze birch borer and exit holes; c) emerald ash borer larva in gallery; d) emerald ash borer egg; e) emerald ash borer pupa.

Known host-tree species

EAB can utilise a wide range of North American, Asian and European species of ash, with varying susceptibility and consequent damage. Some species of North American ash (e.g. green ash, *Fraxinus pennsylvanica*) are particularly susceptible to EAB attack, often with very high rates of mortality, whereas Asian species of ash (e.g. Manchurian ash, *F. mandshurica*, and Chinese ash, *F. chinensis*), from the beetles' native range, are more resistant to EAB attack and tend to suffer only minor damage (unless other stress factors weaken the tree further). It appears that European ash, *F. excelsior*, is a host but is not as susceptible as North American ash species.

There are also records from North America that EAB will attack and successfully complete its development on white fringetree, *Chionanthus virginicus* L., and, in controlled conditions, to a very minor extent on olive, *Olea europaea* (Peterson *et al*., 2020).

Birch trees (*Betula* spp.) are the only documented larval hosts for BBB. Eurasian birch species, including the UK's native silver and downy birch (*Betula pendula* and *Betula pubescens*), are particularly susceptible to BBB attack (Muilenburg and Herms, 2012).

Identification and symptoms

Both EAB and BBB infestations are difficult to detect until the symptoms become severe. Indicators to look for include:

- dying branches and dieback of the foliage, typically from the top (crown) down;
- yellowing and thinning foliage;
- longitudinal fissures between 5 and 10 cm long in the bark, caused by the growth of callus tissue produced by the tree in response to feeding by the larvae;
- epicormic shoots (foliage sprouting from the trunk);
- woodpecker activity – woodpeckers strip away small patches of bark so that they can extract the various life stages of the beetles in the phloem;
- D-shaped holes in the bark, about 3 mm wide, produced by adult beetles as they emerge from the pupal chamber;
- characteristic serpentine larval feeding galleries, which can be exposed when pieces of bark fall or are cut from damaged trees that have been infested

for one or two years. Typical galleries meander, bend sharply, and are packed with frass (the fine, brown, powdery refuse produced by the boring activity, and the excrement of the larvae).

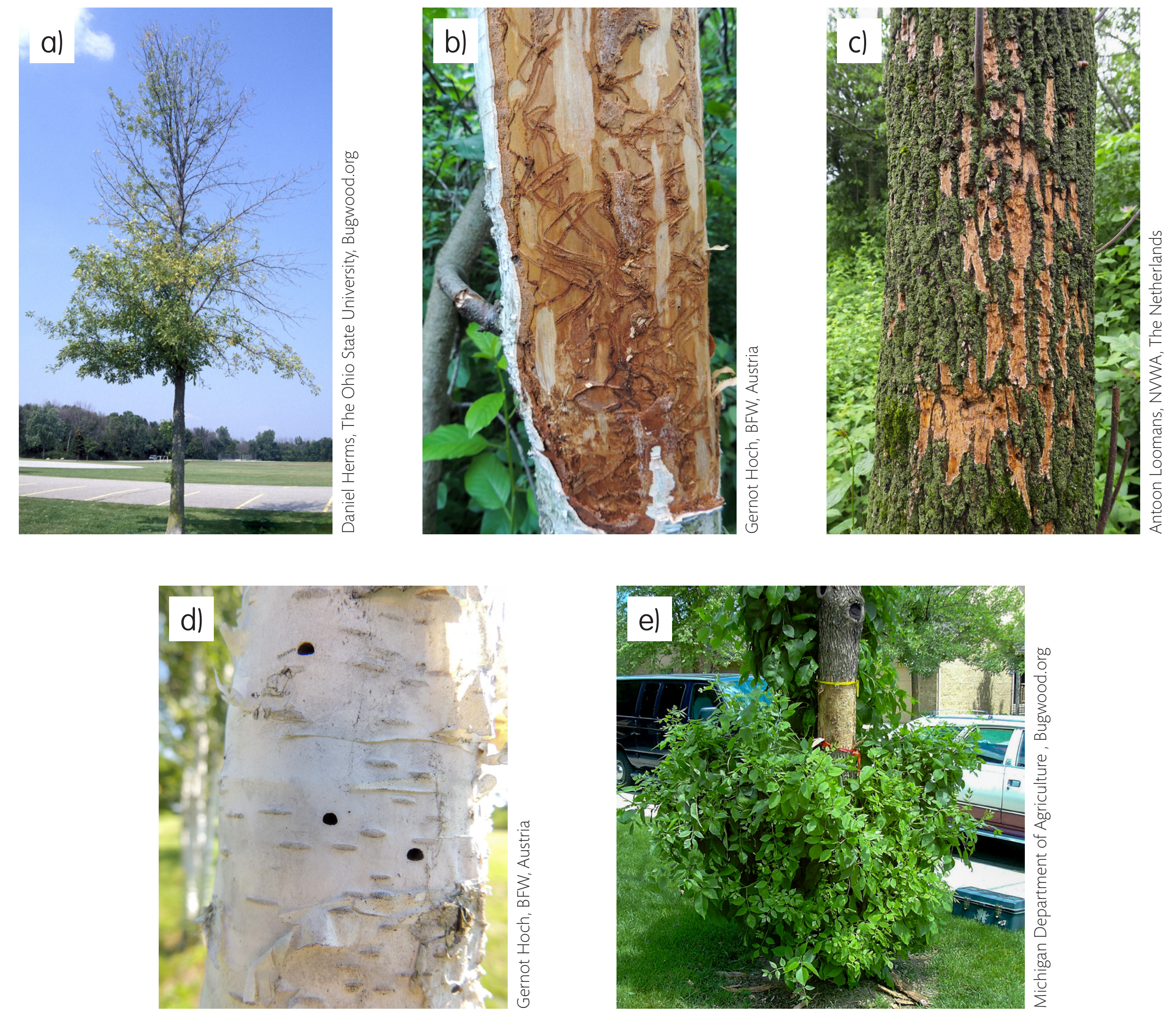
Some symptoms of EAB infestation are similar to those caused by a variety of root and butt rots, which can cause late flushing, thinning foliage and decline leading to eventual death. In Europe, ash trees can also suffer from Chalara ash dieback (caused by the fungus *Hymenoscyphus fraxineus*), which also leads to branch dieback and epicormic growth on stems and in the crown of the tree.

How the pests spread both naturally and by human assistance

Natural dispersal

There has been considerable research into the flight capabilities of EAB, whereas there is very little information on the natural dispersal ability of adult BBB. Based on similarities of size and biology, it is assumed that the description of natural dispersal of EAB would also apply to BBB.

Although flight mill studies in the laboratory suggest that adult beetles can fly for several kilometres, field observations indicate that most



Typical symptoms: a) emerald ash borer damage: yellowing and thinning foliage; b) extensive bronze birch borer larval galleries; c) woodpecker activity on a tree infested with emerald ash borer; d) bronze birch borer D-shaped exit holes; e) emerald ash borer damage: epicormic shoot growth.

flights are within 100–200 m and population spread is less than 1 km per year (Taylor *et al.*, 2010). Infestations therefore tend to be localised and expand gradually over time.

Long-distance dispersal

Human-assisted movement of infested plants and wood products are known pathways for long-distance, including inter-continental, movement of EAB. In all cases, the wood must include the phloem and outer xylem to enable completion of development and emergence of adults at the ends of the pathways. It seems likely that EAB reached North America and the European part of Russia on wood packaging or firewood. Movement of firewood is considered the main pathway for long-distance dispersal in North America and this represents a potentially high-risk pathway for any trade in this commodity from Russia and Ukraine. In addition, hitch-hiking via road vehicles and trains has also been suggested as a significant mechanism by which EAB may potentially achieve long-distance dispersal.

Some consideration has been given to the likelihood of BBB (and EAB) being transported within woodchip shipments from North America to Europe (Flo, Krokene and Okland, 2015). However, the likelihood of detection using current sampling protocols is thought to be close to zero and there is little information on survival of life stages during the woodchip processing stage (Flo, Krokene and Okland, 2014).

Natural and invaded ranges of the pests

EAB global distribution is shown in Figure 2, which includes both its native and invaded ranges.

Figure 3 shows the known range of BBB, which remains in its native North America, with no records of successful invasion to new regions globally.

EAB was first recorded in the US in 2002, but analysis of infestations indicates that it had been present at least from the early 1990s (Siegert *et al.*, 2009). Similarly, EAB was found in Moscow from 2003 onwards but not identified until 2007 and has been in that region since the 1990s (Baranchikov *et al.*, 2008). In both North America and eastern Europe, EAB continues to expand its range mainly through human transportation to more distant locations, then local natural expansion by adult flight. It has recently been confirmed in Ukraine (Drogvalenko, Orlova-Bienkowskaja and Bienkowski, 2019).

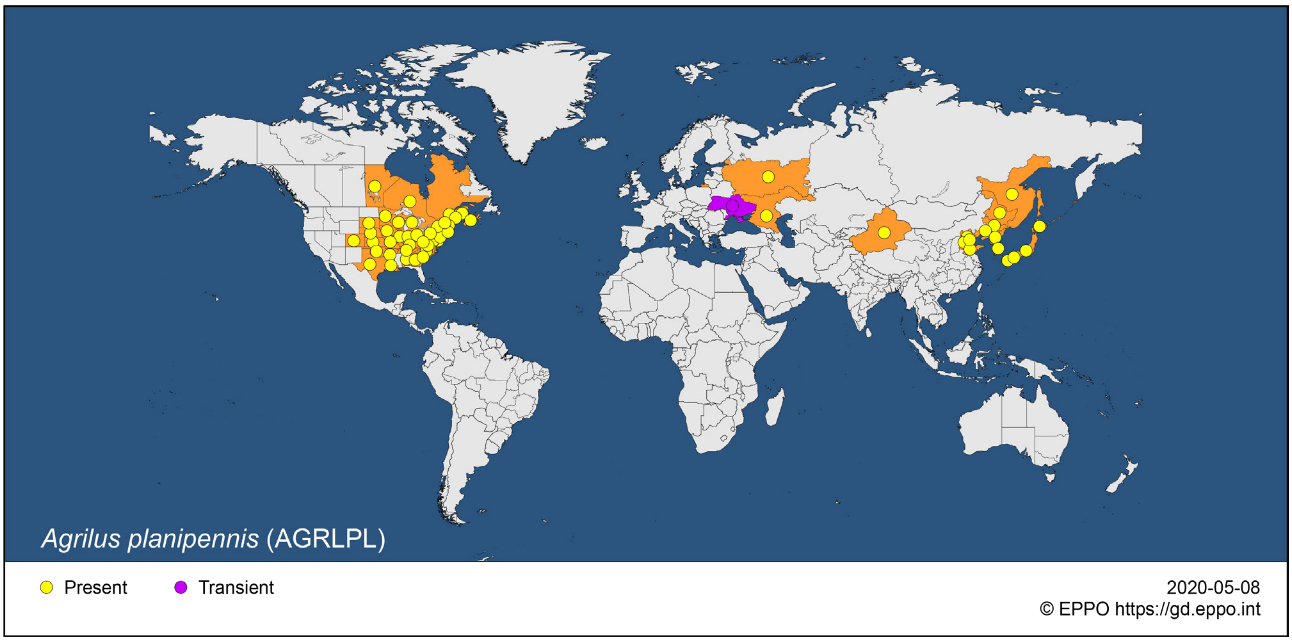


Figure 2 Global map of EAB distribution.

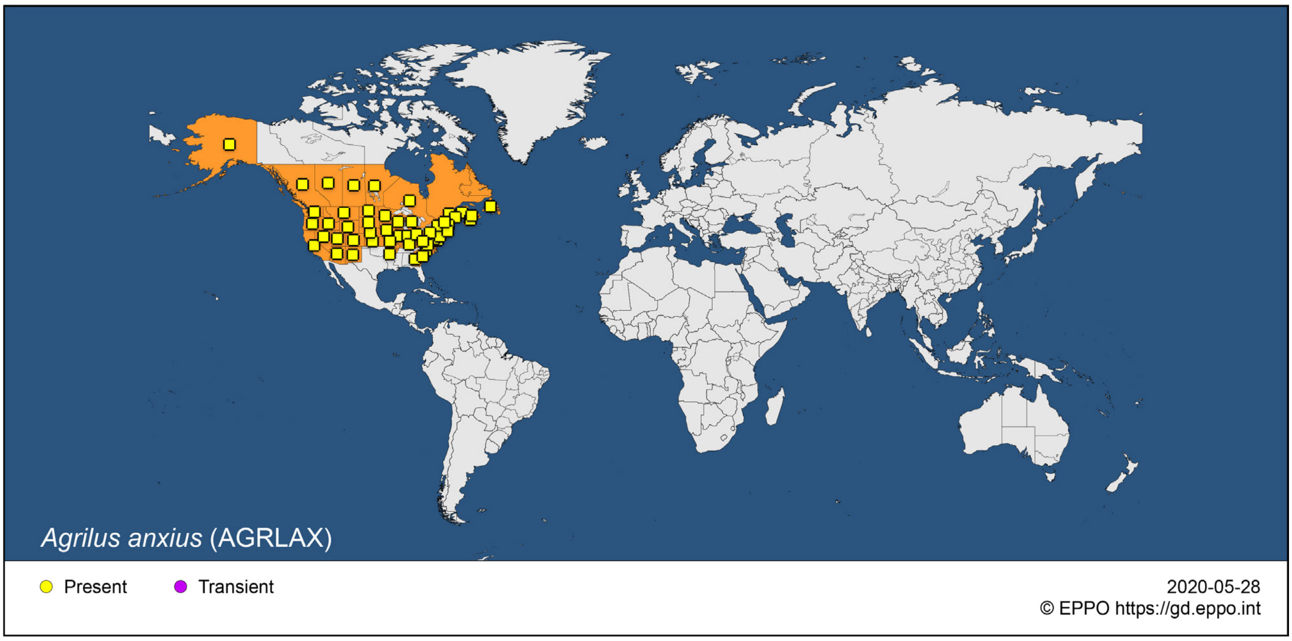


Figure 3 Global map of BBB distribution.

There are no records of interception or presence on birch trees of BBB outside its native range in North America. However, the movement of birch in trade could present a risk.

Economic, environmental and social impacts

Direct and indirect costs of EAB in the US, with the former estimated to exceed US $1 billion annually (Aukema et al., 2011), include tree mortality and the costs of tree removal or insecticide treatment. In the US, socio-economic impacts include loss of ecosystem services and social effects such as reduced well-being and increased crime rates in urban locations (McCullough, 2020). A similar analysis in Canada conservatively estimated losses to be around CAD $890 million (McKenney et al., 2012). In the UK, recent estimates of the cost of Chalara ash dieback suggest about £15 billion (Hill et al., 2019) and EAB could, therefore, significantly add to this total.

Preparing for EAB/BBB invasion: the European Toolbox

Arising from the successful PREPSYS conference in Vienna in October 2018 (www.bfw.ac.at/emeraldashborer) and subsequent papers in the special issue of *Forestry: An International Journal of Forest Research* in April 2020 (https://academic.oup.com/forestry/issue/93/2), the current 'state of the art' has been used to develop a European Toolbox to prepare for and manage EAB and BBB. The Toolbox is outlined below and shown graphically in Figure 4 (Evans *et al.*, 2020), though the majority of information currently applies to EAB.

1. Surveillance effort needs to be very high to have any chance of early detection of EAB invasion and establishment. A wide variety of trapping systems have been tested in North America to detect EAB at the earliest occurrence in any given area and as tools to delimit the boundaries of known infestations. To date, however, there is no single definitive trap design that is regarded as being of optimum efficiency. In Canada, the preference is to use green sticky prism traps baited with the green leaf volatile (3Z)-hexenol and the female-produced sex pheromone (3Z)-lactone, while in the US the preference is for green, Fluon- coated

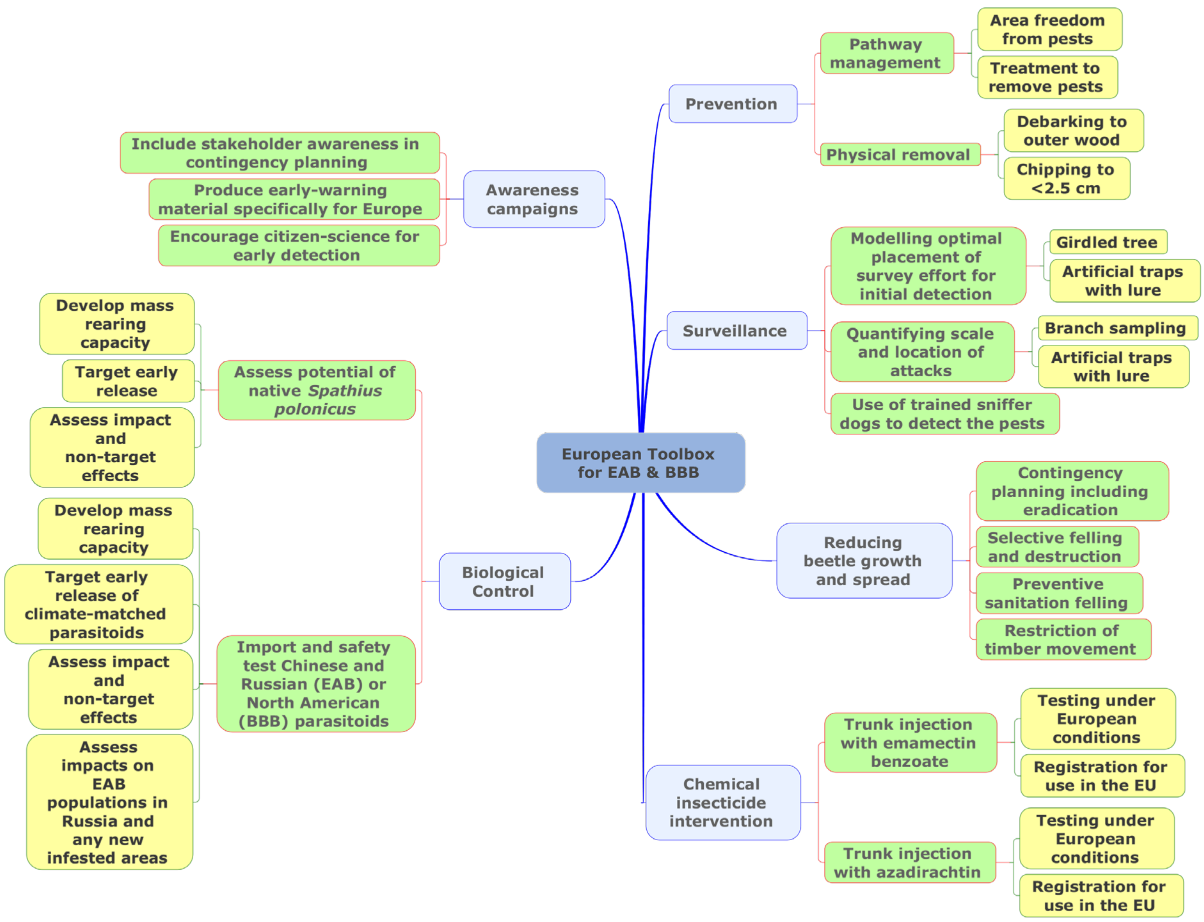


Figure 4 Representation of the main components of a European Toolbox for managing EAB and BBB.

multi-funnel traps baited with (3Z)-hexenol or purple sticky prism traps baited with (3Z)- hexenol. An alternative to artificial trapping systems is the use of girdled ash trees, which are far more attractive to adult EAB or BBB because these trees release chemicals that signal they are stressed and susceptible to attack. This is the most effective method at very low pest densities (Siegert *et al*., 2017). Branch sampling for presence of larvae is a more quantitative method at higher pest densities (Ryall, Fidgen and Turgeon, 2011). The use of sniffer dogs trained to detect EAB has commenced in Austria and offers promise for selective detection of infestations and inspection of transported wood (Hoyer-Tomiczek and Hoch, 2020). Training could be provided for citizen science networks, which will provide an additional resource and 'eyes on the ground' to promote early detection.

2. Increased analysis of pathways (scale and end points) to develop a risk-based optimal surveillance strategy is essential for Europe and could use a similar modelling approach to that developed in North America (Yemshanov *et al*., 2015). The aim would be to place scarce survey resources in the places regarded as presenting the highest risk of arrival of EAB.

3. Slowing tree mortality by trunk injection of emamectin benzoate is an effective underpinning strategy that, although it has limited impact on total pest populations, enables a more gradual use of resources for survey, selective felling and tree replacement (McCullough, 2020). Urgent steps should be taken in the EU to test and register emamectin benzoate for this purpose.

4. Natural enemies are promising for biological control of the pests, but if they are exotic they have a long development

Toolbox suggestions: a) green multi-funnel trap for EAB or BBB surveillance; b) insecticide control of emerald ash borer: trunk injection with emamectin benzoate; c) sniffer dogs trained to detect emerald ash borer; d) biological control of emerald ash borer: the parasitoid *Tetrastichus planipennisi*.

and build-up phase. In North America, after assessment of potential impacts on non-target hosts, four species of parasitoid (parasitic wasps) have been licensed for release in the US and Canada. Three species are larval parasitoids: *Spathius agrili* and *Tetrastichus planipennisi* (both Hymenoptera: Eulophidae) from China and *Spathius galinae* from Russia. The fourth, *Oobius agrili* (Hymenoptera: Encyrtidae), is an egg parasitoid from China (Bauer *et al*., 2015). There are very encouraging signs that released parasitoids have established and are beginning to reduce EAB populations, though care has to be taken to ensure that the species are matched to the most suitable climatic zone for release. Urgent assessment for Europe, including host-range testing and development of mass-rearing capacity, should be carried out. **Inclusion in EU and national contingency planning and policy development is essential and urgent.**

5. Outreach should commence before the pests arrive in Europe. This should be done at many scales from national and regional to local. Information resources should be compiled and made available for pre-emptive and ongoing awareness campaigns. Strong engagement is also needed to build trust and provide robust explanations for management approaches that are taken including their efficacy, longevity and costs (Marzano *et al*., 2020).

6. Awareness campaigns should be informed by social studies that assess how different stakeholder groups will perceive the risks and benefits of EAB and BBB management approaches in order to improve likely social acceptability (Marzano *et al*., 2020). Research suggests that while there is strong support for management of tree pests and disease, pre-emptive felling and insecticide use generally receive little public support. The risk of losing certain valuable ash trees if insecticide is not used may change opinions, and more research is needed on who is likely to reject chemical use and in what contexts. There has also been little research on whether the method of application (e.g. stem injections rather than spraying) makes a difference. Based on evidence from the US, opposition to felling of ash trees in urban residential areas was reduced when residents were offered replacement species.

7. The recent overlap in range between ash dieback and EAB in Russia presents a unique opportunity for study of the

interaction before EAB reaches Europe. Support for joint research into this interaction should be provided urgently.

8. The tools are becoming more effective and sophisticated. However, there needs to be greater coordination and 'ownership' of the Toolbox. EU DG Santé and EFSA (Schrader *et al*., 2020), along with EPPO (Petter *et al*., 2019), are ideally placed to guide action plans and to provide financial and logistic support. NPPOs can influence this process.

Taken together, the components of the Toolbox provide a range of measures that would employ the most effective and up-to-date methods to prepare for and manage the threats posed by EAB and BBB. Early detection is key to putting the management measures into action, and research and development continue to this end.

Acknowledgements

The Euphresco PREPSYS project was supported by the host organisations of the research teams involved in the project. In the UK, the strong support from Defra is gratefully acknowledged. In Austria, the work was supported by the Federal Ministry of Sustainability and Tourism (Project No. 101191).

The International PREPSYS Conference held in Vienna in October 2018 was part-sponsored by OECD's Co-operative Research Programme on Biological Resource Management for Sustainable Agricultural Systems and by Defra, UK. The opinions expressed and arguments employed in this publication are the sole responsibility of the authors and do not necessarily reflect those of the OECD or of the governments of its Member countries.

Support for the final project meeting in Edinburgh was gratefully received from the Scottish Plant Health Centre.

We are grateful to the Euphresco Secretariat for their support throughout the project.

References

Aukema, J. E., Leung, B., Kovacs, K., Chivers, C., Britton, K. O., Englin, J., Frankel, S. J., Haight, R. G., Holmes, T. P., Liebhold, A. M., McCullough, D. G. and Von Holle, B. (2011). Economic impacts of non-native forest insects in the continental United States. *PLOS ONE*, **6**, 1–7.

Baranchikov, Y., Mozolevskaya, E., Yurchenko, G. and Kenis, M. (2008). Occurrence of the emerald ash borer, *Agrilus planipennis*, in Russia and its potential impact on European forestry. *EPPO Bulletin*, **38**, 233–238.

Bauer, L. S., Duan, J. J., Gould, J. R. and Van Driesche, R. (2015). Progress in the classical biological control of *Agrilus planipennis* Fairmaire (Coleoptera: Buprestidae) in North America. *The Canadian Entomologist*, **147**, 300–317.

Drogvalenko, A. N., Orlova-Bienkowskaja, M. J. and Bienkowski, A. O. (2019). Record of the emerald ash borer (*Agrilus planipennis*) in Ukraine is confirmed. *Insects*, **10**, 338–340.

Evans, H. F., Williams, D., Hoch, G., Loomans, A. and Marzano, M. (2020). Developing a European Toolbox to manage potential invasion by emerald ash borer (*Agrilus planipennis*) and bronze birch borer (*Agrilus anxius*), important pests of ash and birch. *Forestry: An International Journal of Forest Research*, 1–10.

Flo, D., Krokene, P. and Okland, B. (2015). Invasion potential of *Agrilus planipennis* and other *Agrilus* beetles in Europe: import pathways of deciduous wood chips and MaxEnt analyses of potential distribution areas. *EPPO Bulletin*, **45**, 259–268.

Flo, D., Krokene, P. and Okland, B. (2014). Importing deciduous wood chips from North America to northern Europe – the risk of introducing bark- and wood-boring insects. *Scandinavian Journal of Forest Research*, **29**, 77–89.

Hill, L., Jones, G., Atkinson, N., Hector, A., Hemery, G. and Brown, N. (2019). The £15 billion cost of ash dieback in Britain. *Current Biology*, 29, 315–316.

Hoyer-Tomiczek, U. and Hoch, G. (2020). Progress in the use of detection dogs for emerald ash borer monitoring. *Forestry: An International Journal of Forest Research*, 93, 326–330.

Jendek, E. and Polakova, J. (2014). *Host Plants of World Agrilus (Coleoptera, Buprestidae). A Critical Review*. Springer, New York.

Marzano, M., Hall, C., Dandy, N., LeBlanc Fisher, C., Diss-Torrance, A. and Haight, R. G. (2020). Lessons from the frontline: exploring how stakeholders may respond to emerald ash borer management in Europe. *Forests*, 11, 617–632.

McCullough, D. G. (2020). Challenges, tactics and integrated management of emerald ash borer in North America. *Forestry: An International Journal of Forest Research*, 93, 197–211.

McKenney, D., Pedlar, J., Yemshanov, D., Lyons, D., Campbell, K. and Lawrence, K. (2012). Estimates of the potential cost of emerald ash borer (*Agrilus planipennis* Fairmaire) in Canadian municipalities. *Arboriculture & Urban Forestry*, 38, 81–91.

Muilenburg, V. L. and Herms, D. A. (2012). A review of bronze birch borer (Coleoptera: Buprestidae) life history, ecology, and management. *Environmental Entomology*, 41, 1372.

Peterson, D. L., Slager, B., Anulewicz, A. C. and Cipollini, D. (2020). Feeding, survival, and fecundity of adult emerald ash borer (Coleoptera: Buprestidae) on foliage of two novel hosts and implications for host range expansion. *Environmental Entomology*, 49, 709–716.

Petter, F., Orlinski, A., Suffert, M., Roy, A. S. and Ward, M. (2019). EPPO perspective on *Agrilus planipennis* (emerald ash borer) and *Agrilus anxius* (bronze birch borer). *Forestry: An International Journal of Forest Research*, 93, 220–224.

Ryall, K. L., Fidgen, J. G. and Turgeon, J. J. (2011). Detectability of the emerald ash borer (Coleoptera: Buprestidae) in asymptomatic urban trees by using branch samples. *Environmental Entomology*, 40, 679–688.

Schrader, G., Ciubotaru, R. M., Diakaki, M. and Vos, S. (2020). EFSA guidelines for emerald ash borer survey in the EU. *Forestry: An International Journal of Forest Research*, 93, 212–219.

Siegert, N. W., McCullough, D. G., Liebhold, A. M. and Telewski, F. W. (2009). Reconstruction of the establishment and spread of the emerald ash borer through dendrochronological analysis, p. 70. In: McManus, K. and Gottschalk, K. (eds.). *19th Annual Proceedings of the USDA Interagency Research Forum on Invasive Species*. General Technical Report NRS-P-36. USDA Forest Service, Northern Research Station, Newtown Square, Pennsylvania, USA.

Siegert, N. W., McCullough, D. G., Poland, T. M. and Heyd, R. L. (2017). Optimizing use of girdled ash trees for management of low-density emerald ash borer (Coleoptera: Buprestidae) populations. *Journal of Economic Entomology*, 110, 1096–1106.

Taylor, R. A. J., Bauer, L. S., Poland, T. M. and Windell, K. N. (2010). Flight performance of *Agrilus planipennis* (Coleoptera: Buprestidae) on a flight mill and in free flight. *Journal of Insect Behavior*, 23, 128–148.

Villari, C., Herms, D. A., Whitehill, J. G. A., Cipollini, D. and Bonello, P. (2016). Progress and gaps in understanding mechanisms of ash tree resistance to emerald ash borer, a model for wood-boring insects that kill angiosperms. *New Phytologist*, 209, 63–79.

Yemshanov, D., Haight, R. G., Koch, F. H., Lu, B., Venette, R., Lyons, D. B., Scarr, T. and Ryall, K. (2015). Optimal allocation of invasive species surveillance with the maximum expected coverage concept. *Diversity and Distributions*, 21, 1349–1359.

Forest Research

Further information

More details of our work on EAB and BBB for the PREPSYS project are available at: www.forestresearch.gov.uk/research/prepsys

Contact details

Hugh Evans, Forest Research: hugh.evans@forestresearch.gov.uk

Mariella Marzano, Forest Research: mariella.marzano@forestresearch.gov.uk

Dave Williams, Forest Research: david.williams@forestresearch.gov.uk

Gernot Hoch, BFW – Austrian Forest Research Centre: gernot.hoch@bfw.gv.at

Antoon Loomans, NVWA – Netherlands Food and Consumer Product Safety Authority: a.j.m.loomans@nvwa.nl

Netherlands Food and Consumer Product Safety Authority
Ministry of Agriculture, Nature and Food Quality

BFW.

Forest Research will consider all requests to make the content of publications available in alternative formats. Please send any such requests to: research.info@forestresearch.gov.uk

Cover image: Jared Spokowsky, Indiana Department of Natural Resources, Bugwood.org

Published by Forest Research, March 2021.

FR(JD-MM)PDF/MAR21-20/0046