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EMERALD ASH BORER: RISK-BASED STRATEGIES TO PEST MANAGEMENT

K. Davydenko[1], Y. Skrylnyk[2], E. Vorobei[3], D. Baturkin[4], V. Meshkova[5]*

Emerald ash borer (EAB) originates from Southeast Asia, since the 1990s it has been widely established across large areas in North America and the European part of Russia. Since 2019, EAB has been found in the Luhansk region of Ukraine and is now present in three regions of Ukraine. The main steps to be taken in case of EAB detection are described. The measures to eradicate the EAB infestations, slow down its spread, and mitigate its impact are revised. The long-term efforts of EAB control in North America could not stop pest spread. Including EAB in the A1 quarantine list of Ukraine also does not allow for preventing the spread of this pest. Suggested measures will not allow for preserving resistant *Fraxinus* sp. genotypes that might otherwise survive. The main methods to control EAB spread and mitigate the consequences of its attacks are those recommended for forest protection against other stem pests. They include in-time surveys and felling infested trees before EAB larvae complete their development.

Keywords: *Agrilus planipennis*, life cycle, host-trees, pest spread, pest monitoring, regulation.

Introduction. The native range of *Agrilus planipennis* Fairmaire, 1888 (Coleoptera: Buprestidae), commonly known as the emerald ash borer (EAB), includes north-east China, Korea, Mongolia, Japan, and the Russian Far East. However, since the 1990s this pest has been widely established across much of North America, the European part of Russia, and Ukraine, where it continues to spread (Davydenko *et al*., 2022; EPPO, 2023; Meshkova *et al*., 2024) in the range of ash (*Fraxinus* spp.) in both continents. EAB attacks various *Fraxinus* species in forests, agricultural landscapes, and other natural and semi-natural habitats, including trees in urban parks and streets. EAB is included in EPPO A2 List of pests recommended for regulation (EPPO, 2013) and on the A1 List of regulated harmful organisms in Ukraine in 2019 (State Service of Ukraine on Food Safety and Consumer Protection, 2019). *This review aims* to raise awareness of the potential threats caused by *A. planipennis*; to provide a field guide on EAB identification and the symptoms caused by EAB; to guide steps to be taken in case of pest detection or signs of EAB attacks; to eradicate the EAB infestations promptly to slow its spread and mitigate its impact, if a population is found to be established.

Materials and Methods. This review is grounded in an extensive analysis of publications in scientific journals worldwide, with a primary focus on the identification, biology, and management strategies for the emerald ash borer. Emphasis was placed on studies offering insights into pest detection, monitoring techniques, eradication efforts, and long-term containment strategies. Additionally, we incorporated findings from our own reviews and scientific papers on EAB and ash dieback in Ukraine, published in recent years. These works provided critical perspectives on the local

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[1] Davydenko Kateryna, PhD, Senior Researcher, Ukrainian Research Institute of Forestry and Forest Melioration named after G.M. Vysotsky, Hryhoriia Skovorody Street 86, Kharkiv, 61024, Ukraine; Swedish University of Agricultural Sciences, P.O. Box 7026, 750 07 Uppsala, Sweden, E-mail: kateryna.davydenko74@gmail.com, ORCID: https://orcid.org/0000-0001-6077-8533

[2] Skrylnyk Yuriy, PhD (Agricultural Sciences), Senior Researcher, Ukrainian Research Institute of Forestry and Forest Melioration named after G.M. Vysotsky, Hryhoriia Skovorody Street 86, Kharkiv, 61024, Ukraine. E-mail: yuriy.skrylnik@gmail.com, ORCID: https://orcid.org/0000-0001-8565-4860

[3] Vorobei Eugene, State Forest Protection Service “Kharkivvlisozakhist”, Nezalezhnosti Street 127, Pokotylivka, 62458, Kharkiv district, Kharkiv region, Ukraine. E-mail: dgordg.vorobey.212@gmail.com, ORCID: https://orcid.org/0009-0001-1961-1245

[4] Baturkin Denys, State Forest Protection Service “Kharkivvlisozakhist”, Nezalezhnosti Street 127, Pokotylivka, 62458, Kharkiv district, Kharkiv region, Ukraine. E-mail: baturkin.denis@ukr.net, ORCID: https://orcid.org/0000-0002-6061-9863

[5] Meshkova Valentyna, Dr. habil. (Agricultural Sciences), Professor, Ukrainian Research Institute of Forestry and Forest Melioration named after G.M. Vysotsky, Hryhoriia Skovorody Street 86, Kharkiv, 61024, Ukraine. E-mail: valentynameshkova@gmail.com, ORCID: https://orcid.org/0000-0001-6483-2736

* Correspondence: valentynameshkova@gmail.com

context, including the unique challenges posed by EAB infestations in Ukrainian ash populations. By integrating global research with regional studies, we aimed to develop a robust understanding of the current state of EAB management and to propose strategies tailored to the Ukrainian context. This combined approach ensures the relevance of the findings and recommendations presented in this review.

Results and Discussion. *Life cycle.* EAB has one generation per year, although under certain conditions it may require two years to complete its lifecycle (EPPO, 2013; Meshkova *et al*., 2023). This depends on the local climate, oviposition timing, food quality, and tree defense response. In total, the pest develops within two years in healthy trees and at low population densities, whereas in stressed trees with higher population densities, it completes its life cycle in one year (Sun *et al*., 2024).

Usually, the life cycle of EAB requires at least 150 frost-free days (with minimum temperatures above zero degrees Celsius) to complete one generation (Wei *et al*., 2007). Thus, the climate of Ukraine meets the conditions necessary for the pest to complete one generation per year. Cold temperatures are not a limiting factor for EAB, as it can survive at temperatures as low as -30°C (Crosthwaite *et al*., 2011). Research performed by the USDA APHIS PPQ (Schrader *et al*., 2020) indicates that an accumulation of 450 growing degree days (base 10°C) is required for the emergence of EAB adults.

Main hosts-trees. The emerald ash borer can cause extensive mortality of ash species and a few other tree species. The only verified larval host plants of *A. planipennis* are those from the genus *Fraxinus* (Jendek and Poláková, 2014) and white fringe tree (*Chionanthus virginicus* L., Oleaceae) (Cipollini and Rigsby 2015).

The following EAB hosts are present in the Ukraine:

– *F. excelsior*, which is widely present in all planted and natural forests, and *F. pennsylvanica* commonly found in forests, shelter belts, and green areas.

– Ornamental species such as *Fraxinus latifolia*, *F. nigra*, *F. ornus*, *F. quadrangulate,* and *F. velutina,* which occur rarely, mostly in arboreta, botanical gardens, parks, etc.

North American ash species are susceptible to EAB even when healthy, whereas Asian species (*F. chinensis*, *F. mandshurica, F. rhynchophylla*) are susceptible only when stressed (Poland *et al*., 2015). Among North American ash species, blue ash (*F. quadrangulata*) is the least vulnerable, and white ash (*F. americana*) is somewhat less preferred than black ash (*F. nigra*) and green ash (*F. pennsylvanica*) (Herms and McCullough, 2014). All European ash species (*F. angustifolia*, *F. excelsior*, and *F. ornus*) are highly susceptible to EAB attack even when healthy (Herms, 2015).

Regulation. The emerald ash borer is listed as a priority quarantine pest in Schedule 1 of The Plant Health Regulations 2020/1482: its introduction into and movement within the EU is banned. EAB is classified as a CU quarantine pest listed in part A of Annex II of Commission Implementing Regulation (EU) 2019/2072 and as a priority pest under Commission Delegated Regulation (EU) 2019/1702. Specific requirements for importing plants, wood, and related products of *Fraxinus* spp. and other host species are outlined in Annex VII of Regulation (EU) 2019/2072. Additional measures have been adopted to prevent EAB entry from Ukraine (Regulation (EU) 2020/12926), while derogations allow the import of certain ash wood from the USA and Canada under strict conditions (Regulations (EU) 2020/1164, 2020/1002, 2020/918).

EAB has been listed on Ukraine's A1 List of regulated harmful organisms since 2019 (State Service of Ukraine on Food Safety and Consumer Protection, 2019). Ukraine has imposed import restrictions on wood, particularly ash firewood from regions where EAB is present and all infested ash trees must be cut and then burnt or chipped. A preliminary risk assessment conducted by the EPPO Panel on Quarantine Pests for Forestry has shown a high probability of EAB establishment in Europe (EPPO, 2013). Therefore, the risk of EAB spreading across all of Ukraine is also high.

The Department of Phytosanitary Safety, Control in the Field, Seed Production, and Plant Nursery is a part of the State Service of Ukraine for Food Safety and Consumer Protection (SSUFSC). The Department carries out field monitoring and is tasked with safeguarding Ukraine from phytosanitary risks, such as those posed by EAB incursions, spread, and outbreaks. It continuously monitors EAB across Ukraine. Additional legislation has been introduced for Ukraine by the SSUFSC, based on the EPPO Standard PM 9/14(1), which recommends maintaining a regulated area of at least 100 km around outbreak areas when implementing a containment policy.

Response. The North American experience shows that EAB eradication from infested regions is challenging. Therefore, the Department of Phytosanitary Safety is focusing on phytosanitary measures to prevent the spread of EAB. Continued military hostilities and the occupation of the eastern regions, where EAB is present, complicate both the eradication and monitoring process. Moreover, the mined territories left by armed conflicts, where access is denied, continue to pose a threat to civilians for many years.

Therefore, there should also be a strong emphasis on detecting the pest in the places of destination of possible pathways, particularly in Central and Northern Ukraine. In the event of EAB introduction, a rapid survey is highly recommended to determine its distribution within the region. Based on the results, a decision should be made regarding whether to pursue the eradication. EPPO recommends that upon first detection of EAB, all feasible measures should be taken to eradicate it (EPPO, 2013).

Spread capacity. The distribution of host trees, such as *F. pennsylvanica* and *F. exselsior,* is important for detecting the pest or delimiting survey areas. At the local level, the potential spread rate of EAB is determined by the distance that the beetle can cover by natural spread in one year. To determine the value of potential EAB spread, the distance an adult beetle can fly from its initial introduction point in one year is essential information for designing a surveillance program.

Under laboratory conditions, EAB adults can fly on average of 1.3 km per day, with some individuals covering more than 7 km per day (Taylor *et al*., 2010). Long-distance movement of adult EAB, involving tens or hundreds kilometres, likely requires human assistance (EPPO, 2023). In addition, Short *et al*. (2019) suggested that EAB could hitchhike on trains or cars. It has also been reported that a small percentage of EAB can emerge from firewood for two seasons after the wood is cut from infested trees (Petrice and Haack, 2007. In the USA, EAB has been estimated to have spread – both naturally and through human assistance – at a rate of 20 km per year during 1998–2006 (Prasad *et al*., 2010).

EAB spread in Ukraine. This pest was officially detected in the Luhansk region in 2019. However, judging by the presence of various larval instars and exit holes, it is presumed that EAB likely entered as early as 2017, probably from the neighboring Voronezh region of Russia. By 2021, the EAB spread throughout the entire Luhansk region and parts of Kharkiv region (Davydenko *et al*., 2022).

The Department of Phytosanitary Safety, Control in the Field, Seed Production, and Nursery is responsible for preventing EAB’s spread in Ukraine, including localization of foci, eradication, and the establishment of quarantine regimes. Such regimes were established in 13,3 ha of the Luhansk region in 2019, 233,9 ha in 2020, and 986.75 ha in 2021. In 2021 quarantine zones were also announced in the Kupiansk District of Kharkiv region. In 2022 the area under quarantine measures expanded in both regions, and EAB was also detected in the parks of Kyiv (Strygun *et al*., 2022).

According to quarantine rules, all ash trees within the affected zones must be eradicated. Therefore, all ash trees within the area of the first confirmed EAB detection in the Luhansk region were cut and burnt in 2019. New pest foci were detected during additional monitoring surveys, and 8.3 ha were localized and eradicated in March 2020 through cutting and burning. Eradication measures continued in 2021 in areas covering 986,75 ha in Luhansk and 177,8 ha in Kharkiv region. These actions were carried out under the supervision of the State Phytosanitary Inspectors in the Luhansk region.

Monitoring. EAB foci are challenging to eradicate because inspecting all ash trees in the region is impossible, and so monitoring will not detect 100% of infested trees. However, it is crucial to locate and eliminate EAB before it becomes established in certain areas. According to EPPO (2023), climate conditions in Europe, particularly in Ukraine, are not a limiting factor for EAB. Both precipitation and temperature are not expected to hinder its establishment. Therefore, the availability of ash trees in Ukraine is the primary indicator of environmentally suitable areas for EAB.

Survey criteria are based on biological characteristics of the EAB, including findings or reports of live or dead beetles in pheromone traps, typical D-shaped exit holes in the bark of ash trunks, characteristic galleries under the bark, and live or dead insects in wood packaging material (or specimens captured by amateur entomologists). Initial reports may come from forest owners, arboriculturists, woodland owners or managers, and professional survey staff (e.g. Regional Departments of the SSUFSC, Forest Protection Services, forest enterprises, etc.).

Surveys should be done following the recommendations and field guidance provided by the Department of Phytosanitary Safety, Control in the Field, Seed Production and Plant Nursery Resources and should focus on the ash stands with the highest likelihood of EAB presence. These include shelterbelts dominated by *F. pennsylvanica*, forest edges of stands dominated by *F. pennsylvanica* and *F. exselsior*, declining ash stands or trees, parks, cities, and the zones near wood-processing yards that utilize ash.

Regional departments of the SSUFSC also carry out annual monitoring using pheromone traps in each region of Ukraine.

In Ukraine, representatives from SSUFSC regional departments collect monthly information about EAB findings from forest and military forest enterprises, communal forest enterprises, local communities, research institutions, universities and other sources. The regional representatives investigate and report confirmed EAB findings to the SSUFSC. The Department of Phytosanitary Safety, Control in the Field, Seed Production and Nursery Resources will manage any outbreak in full accordance with its EAB Contingency Plan.

The response person from SSUFSC regional departments will gather information including the: location, likely origin, host or commodity, level of damage, extent of outbreak, and chance of spread. Based on this information, the Department of Phytosanitary Safety, Control in the Field, Feed Production and Nursery Resources will decide upon the alert status given and implement urgent measures for eradication as described in the EAB Contingency Plan in Ukraine and EPPO standard PM 9/14 (1).

Visual monitoring. Several illustrated guides provide the keys for identifying EAB (Parsons 2008). Typical adult specimens are bright, metallic, emerald green colored overall, with the elytra usually appearing somewhat duller and slightly darker green, 7.5–13.5 mm long, with elongated bodies (Schrader *et al*., 2020). The overall greenish coloration may also have variable amounts of brassy, coppery, or reddish reflections, and larvae have characteristic abdominal trapezoidal segments and a pronotal groove that is posteriorly bifurcated (Schrader *et al*., 2020).

Visual inspection of infestation symptoms is only effective after trees have been infested for several years (Schrader *et al*., 2020; Davydenko *et al*., 2022; EPPO, 2023). Moreover, visual signs become apparent when trees are heavily infested, while many infested trees show no visible symptoms. Exit holes and galleries are not detectable in early infestations (EPPO, 2023). Larval galleries under the bark are typical for the genus *Agrilus* because of their S-shaped, zigzag or serpentine form (Schrader *et al*., 2020). They are more likely to appear on the sun-exposed side of host trees (EPPO, 2023). Woodpecker damage – evidenced by strips of bark removed from the stem by birds and other animals feeding on the larvae – is an important indicator for visual surveillance (Schrader *et al*., 2020; EPPO, 2023). Other symptoms include dying and dead ash trees, epicormic shoots, thinning crowns (observed from late July until leaf-drop in the autumn), wilting (which may occur 3 to 4 years before strong external symptoms develop that could lead to tree death), and crown dieback.

Traps surveillance. Because the larval stages of EAB are difficult to detect, as they develop inside the trees, surveys initially target adult insects. Various detection methods employing traps have been developed, differing in trap type, color, and attractants. The use of girdled ash trap trees with sticky bands has proven effective for detecting EAB at low prevalence. A new detection method employing sentinel trees in high-risk areas is also being developed (Schrader *et al*., 2020).

Trap types. Traps may be multifunnel, prism, or double-decker types. Multifunnel traps consist of a series of connected funnels that lead to a collection cup, with lure vials attached to the trap's center (Schrader *et al*., 2020). These traps are available in various colors and can be attached to tree branches in the canopy (Schrader *et al*., 2020). Prism traps are three-sided structures made of corrugated plastic. The traps are coated with clear insect-trapping glue, hung on branches in the canopy, and can be baited with various lures (Schrader *et al*., 2020). The double-decker traps consist of two corrugated plastic prisms – one green and one purple – attached to a 3-meter-tall polyvinyl chloride (PVC) pipe supported by a T-post (McCullough and Poland, 2017).

Trap color. Colour is an important factor influencing trap captures. However, the response of EAB to different wavelengths of light is likely affected by adult preferences and behavioural activity patterns (Schrader *et al*., 2020). Purple traps typically capture more females than males, while green traps attract more males (Schrader *et al*., 2020).

Trap attractants. Traps may be baited with host volatiles to attract EAB, such as manuka oil and (3Z)-hexenol, and the female-produced pheromone (3Z)-lactone. The green leaf volatile (3Z)-hexenol is highly effective in enhancing trap captures, especially of males (Schrader *et al*., 2020).

Girdled trees with sticky bands. Girdled ash trees with sticky bands may attract EAB adults due to enhanced production of plant stress volatiles (McCullough and Poland 2017; Schrader *et al*., 2020). However, based on the experience of the Canadian authorities in EAB surveillance, bark windows are ineffective at detecting early infestations. Nevertheless, this method can be useful for delimiting pest outbreak areas and can be applied in Ukraine due to its uniformity, cost-effectiveness, and convenience. However, this method is also damaging and destructive to the tree.

Sentinel trees. When performing risk-based surveys for EAB in European ash forests, the use of sentinel trees in high-risk areas can be a valuable tool for early detection. These could include stressed, potted *Fraxinus* trees of the most susceptible species (e.g. *F. pennsylvanica*) or other ash trees (Schrader *et al*., 2020).

Trap deployment in Ukraine. Different detection methods can be integrated into survey strategies appropriate for specific situations or local conditions (McCullough and Poland, 2017). For example, low-value or declining ash trees along fence lines, roads, or forest edges can be girdled and debarked for monitoring purposes. Less expensive prism traps or reusable funnel traps can be used in large-scale systematic surveys. Free-standing double-decker traps may be particularly suitable for high-risk areas, provided they are placed near ash trees and in open spaces where the prisms are exposed to sunlight. Suitable locations include highway medians, railroad corridors, powerline clearings through forested areas, and the perimeter of sawmills and wood waste disposal sites. With regards to the optimal timing for EAB adult trapping, traps should be set just before adult emergence (i.e. at 450 growing degree days). In the USA, USDA APHIS PPQ recommends placing traps from the 1st of May to 30th of September (Schrader *et al*., 2020). It is important to note that all captured adult beetles must be immediately killed by placing them in a vial filled with 70% ethanol, which should be tightly sealed,. Live adults should never be transported from the suspected infestation site.

Distinguishing EAB infestation from ash dieback caused by Hymenoscyphus fraxineus.

Ash dieback, caused by *Hymenoscyphus fraxineus*, is now widespread in Ukraine, and its symptoms may be confused with those of EAB infestation.

Confirming that the presence of EAB will require expert examination of samples and follow-up inspections, particularly to differentiate it from ash dieback caused by *H. fraxineus*. Both EAB infection and *H. fraxineus* infestation can cause foliar wilt and crown dieback. However, the presence of D-shaped exit holes and larval galleries under the bark are key indicators of *A. planipennis,* which are not associated with *H. fraxineus*.

In smaller ash trees and saplings, typical diamond-shaped lesions caused by the ash dieback pathogen are often visible on the main stem, accompanied by dieback of branches and side shoots. However, the lesions may not be easily observable on the stems of larger trees. *H. fraxineus* generally causes diffuse 'tip dieback' across the periphery of the crown of larger trees. Dense clumps of foliage may appear further down the branches as epicormic growth develops. In contrast, EAB infestation typically begins with dieback of one or two branches, usually on the most sun-warmed tree side, followed by general crown thinning. As infestation progresses, epicormic growth emerges lower on the trunk. Another potential sign of EAB is woodpecker activity, as birds strip the bark to feed on larvae. However, the presence of larvae beneath the bark or the characteristic D-shaped exit holes provides definitive confirmation of EAB infestation.

Response. Official action following a presumptive detection.

Strategic actions on suspicion. In Ukraine, representatives from SSUFSC regional departments serve as a primary point of contact for suspected EAB incidents. Their responsibility is to assign a response officer when an incident occurs.

The assigned response officer will gather key information including: location of the suspected infestation, likely origin of the pest, host tree or commodity affected, level of damage observed, extent of outbreak, and potential of further spread. Based on this assessment, SSUFSC departments will determine the alert status (confirmation of EAB presence or absence). If EAB is confirmed, the following measures will be taken: defining the boundaries of the affected area, declaring a state of quarantine, appointing eradication measures for affected landowners (e.g. State Forest Enterprises, United territorial communities) in accordance with Ukrainian legislation, designating a responsible institution or individual to oversee eradication efforts and setting deadlines for reporting on the implementation of eradication measures.

Tactical actions on suspicion. Holding consignments and imposing movement/planting restrictions. Until further investigation is completed, and under a containment notice, no host material or other suspect items shall leave the affected site. All local tree management operations will be halted until the suspected case is fully investigated. The SSUFSC Department will determine the extent of the site under containment. If the detection is linked to traded plants or wood, a tracing process will be conducted both forwards and backward to identify suspect material and, if the pathway is known, to identify other potentially contaminated stock or sites. This includes suppliers of plants, wood and wood products, as well as wholesalers.

Confirming a new outbreak. How is an EAB outbreak identified? An EAB outbreak may be detected through various means, including surveys carried out following the interception of live or dead EAB specimens in wood, wood packaging materials, or imported plants. Still, more likely, an outbreak would be detected through general surveillance programs or following a report from professionals such as scientists, biologists, ecologists, or foresters observing symptomatic ash trees. Symptoms that may indicate an EAB outbreak include: canopy thinning and dieback, tree mortality, suspect insect galleries and damage beneath the bark.

Confirming the presence of EAB requires expert examination of samples and follow-up inspections, particularly to differentiate it from ash dieback caused by *Hymenoscyphus fraxineus*. Infection with *H. fraxineus* is also characterized by foliar wilt and crown dieback. However, the presence of D-shaped exit holes and larval galleries under the bark are two key indicators of the EAB infestation.

If evidence of EAB is found, follow-up inspections should be conducted in line with ISPM 6 guidelines for surveillance to gather essential information, including:

– Likely origin of the pest and, if a consignment of plants or plant products including wood and wood products is suspected as the source, details of other possible destinations should be documented.

– Geographical location and site ownership. This includes details of abiotic factors that might influence the outbreak, such as public access, transport routes, etc.

– Host plants at the site: Identification of infested host species, variety, development stage, etc., and an estimate of the abundance and distribution of potential hosts in the surrounding area.

– Detection and identification details: information on when and how the pest was detected and identified, along with supporting documentation such as photographs of symptoms.

– Level of pest incidence and, where appropriate, identification of life stages present.

– Extent and impact of damage: Specification of the affected parts of the host plants.

– Recent import or movement of host plants into and out of the affected area.

– Movement of people, products, equipment, and vehicles, where appropriate.

– Site accessibility for machinery to remove trees.

– Relevant treatments applied to host plants that may influence symptom development or detection and diagnosis of the pest.

Sampling. To confirm a suspected EAB detection, the samples of insects and infested plant or wood material must be collected for expert identification. While adult specimens are the most useful for rapid identification, all life stages should be collected if present. A representative sample of the infested plant or wood product should be collected by a representative person of SSUFSC regional departments, including a sample of any attached foliage and bark, to help confirm the identity of the infested material). These samples should then be examined in the SSUFSC Laboratory to verify the presence or absence of EAB.

Diagnostic protocol. The most effective diagnostic protocol for EAB identification involves a combination of visual inspection, trap monitoring, and potentially using specialized tools like tree borer traps or pheromone traps. Identification of EAB is based on morphological characteristics and/or DNA sequencing of adults, larvae, or pupae. Adults of EAB can be identified by comparing the taxonomic keys (Parsons, 2008; EAB network, 2016). Samples should only be removed from the site by trained personnel using appropriate equipment while adhering to biosecurity guidelines.

Official actions following the confirmation of an EAB outbreak. Once an EAB infestation is confirmed, immediate action is required to control the spread and minimize damage to ash tree populations. The response will depend on the extent of the outbreak, local regulations, and the management strategies.

Quarantine Measures (mandatory). If EAB is detected in a specific area, quarantine measures must be implemented to restrict the movement of potentially infested ash materials, such as logs, branches, or nursery stock, to prevent the beetle's spread to new areas.

Tree Removal and Disposal. Infested trees should be removed and properly disposed to prevent the beetles from spreading to neighbouring trees and reduces the overall population of EAB in the area. Depending on local regulations and management strategies, the removed trees may need to be chipped, burned, or buried to ensure the beetles are killed.

Chemical Treatments. Insecticide treatments can be applied to protect high-value individual ash trees from EAB infestation. These treatments typically require trained professionals and may involve trunk injections, soil drenches, or spray applications. The guidelines and recommendations for the specific insecticide being used must be followed.

Biological Control. In some cases, introducing natural predators or parasitosis of EAB can be an effective strategy for managing the beetle population. However, this approach often requires further long-term study to identify efficient biological agents in Ukraine and careful evaluation of potential risks to the local ecosystem. Biological control may not be suitable for all environments.

Monitoring and Surveying. Continue monitoring is crucial for early detection of new infestations. Regular surveys and inspections of ash trees can help identify new EAB populations and assess the effectiveness of management efforts.

Public Awareness and Education. Raising awareness among landowners, foresters and the public is essential for early detection and control. Educating people about the signs of infestation and the importance of taking appropriate action can help in the overall efforts to slow the spread.

Ash Tree Replacement and Diversification. In areas where EAB has caused significant damage and the ash tree population is severely affected, reforestation and species diversification can help restore ecological balance and reduce vulnerability to future pest outbreaks. This involves replanting with alternative tree species to enhance biodiversity and encouraging the use of resistant or non-host species.

Working with local forestry departments, agricultural extension offices, certified arborists, and other experts experienced in managing EAB infestations is essential. These professionals can provide guidance tailored to the specific situation and help implement the most effective and environmentally responsible strategies for EAB control. Early detection and swift action are keys to minimizing the damage caused by this destructive invasive species.

Demarcated zones. A statutorily regulated area should be established immediately after an EAB outbreak, to help minimize the spread of the pest within the infested area, and to prevent human-assisted transport of infested material to unaffected regions. An initial regulated area around the infested trees must be established, within which measures avoiding the movement of potentially infested ash material should be implemented. These measures should include a prohibition on the movement of untreated ash wood (including firewood, round wood, sawn wood, wood chips, waste wood, and arboricultural arisings) and ash plants for planting purposes. The prohibition should prohibit the movement of such material from the infested area to the rest of the regulated area, and from the regulated area to regions outside the regulated area. If new EAB detections occur, the regulated area may need to be expanded to include previously unaffected zones.

Management strategy. The response strategy will focus on eradication and containment, depending on the number of infested trees, whether adult beetles have emerged, the number of pest generations completed, the distribution of infested ash trees, and the density of ash trees in the surrounding area.

Pest management procedures.

Surveillance. Following an EAB interception, if no infested ash trees are found during the initial delimiting survey, the area may be declared free of tree infestation, and there is no immediate risk of pest spread, therefore a moderate surveillance program must be implemented (Fig 1).

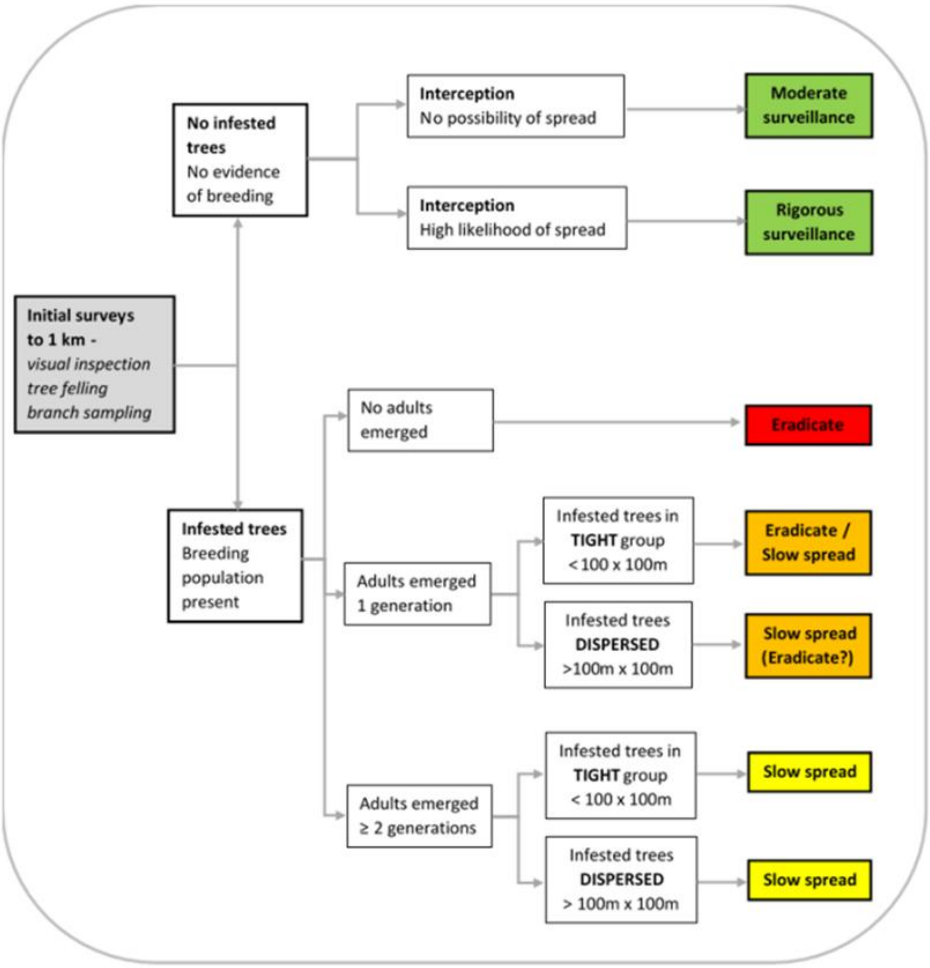

Fig. 1 – Management strategies for *Agrilus planipennis*

It consists of annual repeated surveys of the original 1 km intensive survey zone, combined with adult beetle trapping and using of girdled trap trees. These follow-up surveys must be repeated annually for at least 2–3 years.

If the initial delimiting surveys do not detect infested ash trees, but there is a high likelihood that adult beetles have spread into the wider environment, a more rigorous surveillance plan must be implemented. It should involve repeating the intensive surveys outwards to 1 km and the line transect surveys to 10 km in the following and subsequent years and establishing a network of traps and girdled trap trees. The number and placement of traps and girdled trees will depend on the abundance and distribution of ash trees in the surrounding area. These surveys must continue for at least 3 years.

Eradication. If the initial delimiting surveys detect infested ash trees, the decision either to either attempt eradication or focus on slowing the pest's spread and reducing its impact will depend on whether adult EAB have already emerged from the infested trees and how long the beetles have been present. If no adult beetles have emerged, or if only one generation of beetles has emerged and their ability to spread appears limited, eradication may be possible, and management efforts should prioritize this goal. An infestation confined to a small group of trees in an area where with few ash trees is more likely to be eradicated than one affecting a larger number of trees dispersed across a wider area – especially if there many other ash trees present in the surrounding environment. Determining how many generations of beetles may have emerged and how far they might have spread will require a detailed examination of infested trees by entomologists specializing in xylophagous insects.

Actions focused on eradication should include:

Felling and destroying (chipping/burning) all ash trees outwards the infested trees. This suggestion is based on Mercader *et al*. (2012) who found that 90% of EAB larvae were located within 100 m of the point where adults emerged in newly established satellite populations, and 98% of larvae were found within 200 m. Less than 1% of larvae were found beyond 400 m from the point of adult emergence. However, such measures failed to stop the spread of EAB in the USA. Unlike the USA, in Ukraine, EAB-attractive trees grow primarily in forest shelterbelts and urban green spaces. They are significantly represented in forest areas only in the southeastern regions. Studies in the Luhansk region (Meshkova *et al*., 2024) showed that EAB occurrence is most probable in the driest forest site conditions, the warmed-up areas within stands, especially small subcompartments surrounded by non-forest landscapes, and forest shelter belts near roads and fields. The EAB spread from the Luhansk region through such plantings to the Kharkiv region and then further to Kyiv, following roadside shelterbelts.

The use of trap trees. Girdled ash trees are highly attractive to adult EAB, and if these trees are treated with an insecticide, all life stages of the pest can be eliminated (McCullough and Poland, 2017).

Traps for adult beetles. Green or purple traps, baited with the host volatile (z)-3-hexanol, can be used. However, traps are less effective when populations are low and are generally more useful for monitoring rather than reducing the EAB population.

If the infested trees are detected during the beetles' flight period, they must be removed and destroyed as soon as possible to limit adult emergence and dispersal. However, sufficient time must be allowed for a thorough investigation to determine how long the beetles have been present and how far they may have spread. Outside the flight period, from July through April, trees can be felled and removed at any time. However, it is crucial to clear and destroy all infested trees before the next flight period begins (i.e., before the beginning of May).

Trees should be cut as close as possible to ground level. Trunks and branches should be cut into sections small enough to be easily handled, turned over, and inspected before disposal. Logs and the bark from the basal 50 cm of at least two branches per tree must be inspected for galleries and immature life stages of EAB.

In the following year, intensive surveys and trapping should be conducted from the edge of the clear-felled area to the boundary of the designated infested area. Additionally, trapping and systematic surveys extending outward to 10 km, must be repeated to confirm whether there has been any further spread. If more infested trees are discovered, the infested area and the boundaries of the regulated area must be refined accordingly. If additional infested trees are found, all ash trees within a radius of 500 m must be felled and removed, as detailed above.

This process must be repeated for at least four years until the last infested trees have been removed. If no new signs of EAB breeding are detected, the infestation may be declared eradicated. However, this period could be shortened or extended depending on whether newly infested trees continue to be found and the pest continues to spread. If the spread persists, a policy shift from eradication to containment may be necessary.

Traps designed to capture EAB adults have been developed in the USA and Canada, and establishing a network of traps across the infested and regulated area will help monitor occurrence and spread. In the USA, purple sticky delta traps baited with (Z)-3-hexanol, or green multi-funnel traps baited with the same compound are recommended. In Canada green delta traps baited with the green leaf volatile (Z)-3-hexanol have proven effective.

To maximize EAB capture, traps must be placed in sunny, exposed locations, preferably on the southwestern side of trees. Free-standing 'double-decker' traps were found to be more effective at capturing EAB adults at low populations than single traps placed in trees (McCullough and Polland, 2017). In contrast, trap logs were ineffective, as EAB prefers to attack living trees rather than felled wood.

Girdled trees are more effective than artificial traps at detecting low-density EAB populations. However, as EAB density increases, the difference in effectiveness between girdled trees and artificial traps diminishes. Girdling is performed in spring or early summer by removing a 15–20 cm band of outer bark and phloem around the tree base. This is followed by felling and debarking in the autumn or winter to detect larval galleries. To prevent further beetle emergence, girdled trees must be felled and destroyed before the start of the next flight period. Small to medium-sized trees (10–20 cm DBH) are optimal for girdling, as they are easier to girdle and inspect and highly attractive to EAB oviposition (McCullough and Polland, 2017).

Slowing spread and reducing impacts.

If infested ash trees are found with more than one generation of adult beetles emerged and dispersed (Figure 1), it is likely that EAB eggs have been laid in ash trees beyond 1 km from the initial infestation site. Locating these infested trees becomes increasingly difficult. EAB is a strong flyer, capable of traveling distances greater than 1 km, and can also spread through transport (Short *et al*., 2019).As a result, once more than one or two generations of beetles have emerged, clear-felling outward to 1 km will neither eradicate nor prevent further spread of the pest, particularly in regions experiencing active hostilities.

Climate change and associated hot summers accelerate EAB development and spread. Experience in North America has shown that clear-cut areas ultimately do not prevent EAB spread, except perhaps in the very earliest stages of an outbreak. Additionally, selective and clear felling may remove resistant ash genotypes that could have otherwise survived. Cutting large numbers of infested or potentially infested trees depletes local resources for the pest, which may stimulate its spread to new areas. Given these factors, we believe including EAB in the "A1 List of Pests Recommended for Regulation as Quarantine Pests" in 2019 was a significant mistake, as exit holes were already visible at that time. This suggests that EAB infestation began no later than 2017. Implementing quarantine measures in the Luhansk region based on the A1 List requirements was ineffective in stopping further expansion of the outbreak.

Therefore, when the infestation is more extensive, and more than one generation of adult beetles has emerged and dispersed, the management program should prioritize monitoring and phased removal of the most severely affected ash trees. This approach aims to reduce the EAB population and slow its spread (Figure 1), particularly during the flight period.

By removing only the most affected trees, this strategy preserves potentially resistant ash trees that may survive despite the infestation and maintains populations of natural enemies (parasitoids, predators, and entomopathogens), which could contribute to long-term EAB population control.

Annual surveys are essential to track the spread of EAB, redefine infested areas and adjust the boundaries of regulated zones, and differentiate EAB-infested trees from those affected by ash dieback (caused by *H. fraxineus*).

Likewise, four species of Asian parasitoid wasp – *Spathius agrili*, *Sp. galineae*, *Tetrastichus planipennisi* and *Oobius agrili* – have been released in the USA as biological control agents against EAB larvae (Sun *et al*., 2024). However, their effectiveness in Ukraine remains unknown.

Recovery. Eradication is unlikely if EAB has spread into the wider environment, except under highly restrictive conditions. Therefore, full recovery to pre-outbreak conditions is not feasible. To restore woodland and urban landscapes, alternative tree species could be planted. Replanting with EAB-resistant ash may also be an option if resistant genotypes can be identified and propagated. However, any replanting efforts must also consider resistance to ash dieback.

Conclusions.

EAB is a highly destructive alien pest that has already infested three regions of Ukraine, threatening *Fraxinus* species.

The review outlines key steps to take following EAB detection or symptoms of infestation, methods for eradicating the EAB infestations and slowing the pest's spread, and strategies to mitigate EAB's impact if an established population is found.

Long-term efforts to stop EAB spread in the USA have been unsuccessful. Listing EAB on the A1 Quarantine List does not prevent its expansion. Furthermore, rigid regulatory measures may hinder the preservation of resistant ash genotypes that could otherwise survive. The most effective mitigation strategies align with standard forest protection methods against other stem pests. They include timely surveys to detect new infestations and felling infested trees before EAB larvae complete their development.

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ЯСЕНОВА СМАРАГДОВА ВУЗЬКОТІЛА ЗЛАТКА: СТРАТЕГІЯ КОНТРОЛЮВАННЯ З УРАХУВАННЯМ РИЗИКУ

Давиденко К. В.[1], Скрильник Ю. Є.[2], Воробей Є. В.[3], Батуркін Д. О.[4], Мєшкова В. Л.[5]*

Ясенова смарагдова вузькотіла златка (ЯСВЗ) походить із Південно-Східної Азії, із 1990-х років широко розповсюджена на великій території Північної Америки та європейської частини Росії. З 2019 р. ЯСВЗ виявлено в Луганській області України, і наразі вона поширена в трьох областях України. Описано основні дії, які необхідно вжити у разі виявлення ЯСВЗ. Переглянуто заходи щодо ліквідації осередків ЯСВЗ, уповільнення її поширення та послаблення впливу. Довгострокові зусилля з контролю ЯСВЗ у Північній Америці не змогли зупинити поширення шкідника. Внесення ЯСВЗ до карантинного списку А1 України також не дає можливості запобігти поширенню цього шкідника. Запропоновані заходи не дають змоги зберегти стійкі генотипи *Fraxinus* sp., які інакше могли би вижити. Основними методами контролю поширення ЯСВЗ і пом'якшення наслідків її нападів є такі, що рекомендовані для захисту лісу від інших стовбурових шкідників. Вони охоплюють своєчасні обстеження та вирубування заселених дерев до того, як личинки ЯСВЗ завершать свій розвиток.

Ключові слова: *Agrilus planipennis*, життєвий цикл, дерева-живителі, поширення шкідників, моніторинг шкідників, регулювання.

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[1] Давиденко Катерина Валеріївна, PhD, доцент, Український науково-дослідний інститут лісового господарства та агролісомеліорації ім. Г. М. Висоцького, вул. Григорія Сковороди, 86, Харків, 61024, Україна; Шведський університет сільськогосподарських наук, а/с 7026, 750 07 Уппсала, Швеція. E-mail: katerуna.davydenko74@gmail.com, ORCID: https://orcid.org/0000-0001-6077-8533

[2] Скрильник Юрій Євгенович, канд. с.-г. наук, старший дослідник, Український науково-дослідний інститут лісового господарства та агролісомеліорації ім. Г. М. Висоцького, вул. Григорія Сковороди, 86, Харків, 61024, Україна. E-mail: yuriy.skrylnik@gmail.com, ORCID: https://orcid.org/0000-0001-8565-4860

[3] Воробей Євген Віталійович, Державне лісозахисне підприємство "Харківлісозахист", вул. Незалежності, 127, пмт Покотилівка, 62458, Харківський р-н, Харківська обл., Україна. E-mail: dgordg.vorobey.212@gmail.com, ORCID: https://orcid.org/0009-0001-1961-1245

[4] Батуркін Денис Олександрович, Державне лісозахисне підприємство "Харківлісозахист", вул. Незалежності, 127, пмт Покотилівка, 62458, Харківський р-н, Харківська обл., Україна. E-mail: baturkin.denis@ukr.net, ORCID: https://orcid.org/0000-0002-6061-9863

[5] Мєшкова Валентина Львівна, доктор сільськогосподарських наук, професор, Український науково-дослідний інститут лісового господарства та агролісомеліорації ім. Г. М. Висоцького, вул. Григорія Сковороди, 86, Харків, 61024, Україна. E-mail: valentynameshkova@gmail.com, ORCID: https://orcid.org/0000-0001-6483-2736

* Адреса для кореспонденції: valentynameshkova@gmail.com