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# Early warning early action systems for invasive alien species affecting forests in Europe and Central Asia: an overview

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Early Warning Early Action (EWEA) is a system and set of protocols developed and implemented by the Food and Agriculture Organization (FAO) as part of its disaster risk reduction and resilience work. EWEA provides proactive approaches to predictable shocks by investing in monitoring and disaster management for different humanitarian and ecological crises around the world. As the rate of spread of invasive alien species (IAS) increases and disrupts the vital ecological functions in forests around the world, vigorous phytosanitary protocols are needed to prevent and mitigate their dispersal and adverse impacts. The anticipatory approach of EWEA systems is well-suited for mitigating the detrimental effects of IAS, as preventive measures have proven to be the most effective. In this review of EWEA for forest IAS, papers have been categorized into six themes: a review of EWEA systems, sentinel tree species in plantations and gardens, trapping and detection methods and their application, pathways of IAS introduction, citizen science for early detection, and modeling of EWEA systems. Additionally, a survey was conducted among researchers and forest managers to determine their perspectives in relation to EWEA systems. A total of 96 respondents (58 from Europe and 38 from Central Asia) provided information that complements the review findings. The results indicate that EWEA systems are generally recognized as an optimal approach to contain threats posed by IAS in various types of forest ecosystems. The complex and dynamic pathways of IAS require a multi-faceted management approach that draws on each of these themes. Continual monitoring at local and macro-regional levels must be coupled with harmonized and consolidated phytosanitary measures at the regional and global levels in order to build EWEA systems that would effectively tackle the spread of IAS.

## KEYWORDS

citizen science, detection, modeling, pest, sentinel tree, trapping

## 1 Introduction

Invasive alien species (IAS) are plants, animals, pathogens, and other organisms that are non-native to an ecosystem, and which may cause economic or environmental harm or adversely affect human health (CBD, 2026). IAS pose serious threats to natural and planted forests. They impact forest health, productivity, and biodiversity and burden ecological systems

and processes by disturbing the functions of forests (Noar et al., 2021; Paap et al., 2020; Ribaya et al., 2025). Preventative measures are considered highly effective both ecologically and economically; however, proactive management worldwide is far from being sufficient, and thus post-invasion expenditures are still dozens of times higher than pre-invasion management (Cuthbert et al., 2022).

We are seeing an unprecedented exchange of products across global networks, be it through travel or trade, and thus the introduction and spread of IAS are accelerating (Japelj et al., 2019; Rosace et al., 2023). Increased trade pathways, changes in land use patterns, and environmental shifts caused by climate change all have a hand in the increasing threat of IAS (Pautasso, 2015). Ultimately, the damages caused by IAS also burden the cultural and economic systems that rely on forests and have caused an estimated US\$1.4 trillion annually in global losses (Noar et al., 2021). Due to the dynamic nature of IAS introduction pathways, a multi-dimensional and harmonized approach is necessary to combat this growing issue.

Early Warning Early Action (EWEA) systems are facilitated by the Food and Agriculture Organization of the United Nations. EWEA covers anticipatory action plans, which enable “FAO to act early before disasters have happened and to mitigate or even prevent their impact. By lessening damages to livelihoods and protecting assets and investments, FAO can help local livelihoods become more resilient to threats and crises” (FAO, 2020). Not only have EWEA systems proven to be an efficient way to support communities, but they have also proven to be financially astute (FAO, 2021). One example of an EWEA system is the *Global Action for Fall Armyworm Control*, a program developed by the FAO that provides guidance for the control and eradication of *Spodoptera frugiperda* (Lepidoptera: Noctuidae), an insect pest threatening crops in various parts of the world, as well as organizes a Pest Risk Assessment (PRA) and alert systems (IPPC, 2022).

The review and the survey presented here aim to collect and communicate EWEA systems currently in place in Europe and Central Asia (as well as in other countries with applicable action plans) that work to prevent or eradicate invasive species in forest regions. A specific aim is to provide a comprehensive overview of the EWEA systems implemented in the study region that has scientific value and can serve as a robust foundation for experts, as well as improve the knowledge and preparedness of plant protection organizations in Europe and Central Asia for future IAS outbreaks in their forests.

## 2 Methods

### 2.1 Review

The review was based on a systematic analysis of literature for both macro-regions (Europe and Central Asia), following a uniform approach: the sources were retrieved from the databases Scopus and Google Scholar with a set of search strings with synonyms for Early Warning Early Action followed by insect\* AND invasive OR pest\* followed by AND forest\* AND Europe/Central Asia, from the earliest data available and until December 2022. Papers in both citation databases were ranked by ‘Relevance’ (a parameter set independently by Scopus and Google Scholar, see Rovira et al. (2019) for further description) and downloaded to an Excel sheet for categorization. The results of this preliminary search showed far fewer hits in Scopus than in Google Scholar; the top 100 hits from each search revealed many of

the same papers, and thus, we focused on the citations from Scopus. Two further search strings were added to include papers that refer to ‘fung\*/pathogen’ and ‘invasive pest’. To further refine the scope of the review, a maximum of 100 abstracts were examined and retrieved from each of the four search strings (i.e., 400 and 272 abstracts were screened in total for Europe and Central Asia, respectively), as per the study objectives. Subsequently, the search strings targeting Central Asia were excluded, as a substantial number of relevant publications identified through the Europe-focused search were also captured in the Central Asian search. Therefore, we have extended the analysis of the papers published in national languages.

For Central Asia, where many countries use the Russian language, the literature search was additionally performed in Russian. It was also done because many publications in the national language are not indexed in Scopus or Google Scholar. The national electronic library (E-library, <https://elibrary.ru>) was used as the main search platform, which stores publications (research papers, proceedings, conference communications) in Russian and English. The following search strings were utilized: «раннее выявление, насекомые, вредители леса (i.e., early detection, insects, forest pests)», «раннее выявление, фитопатогены, древесные растения (early detection, phytopathogens, woody plants)», «насекомые - вредители леса, инвазии (insects, forest pests, invasions)», «фитопатогены, инвазии (phytopathogens, invasions)», «мониторинг, инвазивные насекомые, древесные растения (monitoring, invasive insects, woody plants)», «мониторинг, инвазивные фитопатогены, древесные растения (monitoring, invasive phytopathogens, woody plants)», «деревья-стражники (sentinel trees)», and «защита и карантин растений (plant protection and quarantine)». In cases where full versions of targeted publications were not available, the authors were contacted directly by email to share the publications.

Bearing in mind the variability of keywords and multiple synonyms of some terms used in Russian literature, an extensive search of research publications published in the last 13 years (2010–2022) in the leading journals covering various aspects of biological invasions was conducted: («Защита и Карантин Растений, i.e., Plant Protection and Quarantine; <http://www.z-i-k-r.ru/>»), «Российский Журнал Биологических Инвазий (Russian Journal of Biological Invasion, [http://www.sevin.ru/invasjour/issues\\_contents.html](http://www.sevin.ru/invasjour/issues_contents.html))», and «Карантин Растений. Наука и Практика (Plant Health. Research and Practice), which was renamed in 2020 to «Фитосанитария. Карантин Растений (Plant Health and Quarantine), <https://phytosanitary.vniikr.ru/jour/issue/archive>» to find papers that may have been missed during the standard search using the search strings mentioned above.

In addition, an expert survey on the procedure for organizing monitoring of quarantine species in the territory of the Russian Federation was conducted via the website of the Ministry of Agriculture of the Russian Federation.<sup>1</sup>

### 2.2 Survey

The survey was created and disseminated using Google Forms and was written in both English and Russian in 2022. The survey included general information about the interviewees (country, occupation, age, and gender) and 12 questions regarding different aspects of EWEA, in

<sup>1</sup> <https://mcx.gov.ru/>

particular inquiring into the awareness of EWEA systems currently in place as well as awareness of high-risk IAS in Central Asia and Europe (Supplementary File 1). The objective of this survey was to complement the literature review on EWEA and to define priorities for forest professionals in Europe and Central Asia.

It was sent to approximately 200 experts in Central Asia and 100 in Europe. This also included members of the FAO regional network for forest invasive species in Europe and Central Asia as the main platform. REUFIS<sup>2</sup> was used to disseminate the survey to forest specialists in Europe and Central Asia. Additionally, the survey was circulated among contact persons in national Forest Protection Centers, national and regional Centers for Plant Quarantine, forest institutions, and universities, as well as distributed through mailing lists of national and international conferences on forest protection, forest entomology, and phytopathology.

To assess the responses, each individual response was evaluated, and all were considered acceptable. The Russian responses to the survey were translated into English for the analysis. Certain questions with short- and long-answer responses were assessed individually and then categorized and grouped with similar responses. The last multiple-selection questions, regarding risky IAS, were further analyzed by macro-region. This is an important aspect for understanding where and why certain IAS are considered higher-risk by forest professionals.

## 3 Results

### 3.1 Review

#### 3.1.1 EWEA systems

A common goal of EWEA structures is to draw attention to IAS before they are introduced to a new region so that targeted inspection efforts and policy decisions can be effectively implemented (Noar et al., 2021). Forest, agricultural, and semi-natural environments can have overlapping systems of reporting on IAS. Some examples of international organizations that do so include the International Plant Sentinel Network<sup>3</sup> and the International Plant Protection Convention,<sup>4</sup> as well as transnational structures such as the European and Mediterranean Plant Protection Organization<sup>5</sup> and national plant protection organizations (NPPOs) of individual countries. While some of these organizations have general plant health goals, others focus more directly on forests.

Due to the increasing prevalence of IAS via trade pathways, Noar et al. (2021) recommend increasing the interconnectedness of EWEA forest management systems on a global scale, so that various nations and trans/international organizations can synergistically document and identify high-risk IAS. However, interconnectedness between nations and regions requires a restructuring of international guidelines and additional data standards that are not currently in place (Rainford et al., 2020). Relevant information for efficient

biosurveillance must be globally accessible and harmonized into a common framework (Rainford et al., 2020). Unfortunately, for many nations, the required funding is insufficient. IAS awareness and support tend to be low (Rainford et al., 2020) and often underfunded (Japelj et al., 2019; de Groot et al., 2020; Cuthbert et al., 2022). One aspect of cost-effective IAS management that was echoed in many of the publications from this review is that preventing an IAS at or before ports of entry is crucial, as the cost of eradicating an IAS increases once they have established themselves within a forested area.

The EPPO created an *alert list* for IAS in 1999, and it continues to be updated “as new potential phytosanitary problems are identified” (EPPO, 2026). The list relies mainly on literature selected by the secretariat, but also on a network structure of member countries from Europe and the Mediterranean. Those member countries may submit potential plant health risks observed in their own nations to “achieve early warning”. The range of IAS pertains to plant health risks in agriculture, forestry, and semi-natural environments. The recommendations made by the EPPO can be used by countries to develop their own risk assessments and IAS regulations. The EPPO encourages harmonization of those regulations among its members in EU and non-EU countries. De Groot et al. (2020) looked at Early Warning Rapid Response (EWRR, synonymous with EWEA here) systems established specifically for forests in Europe. By looking at the invasion pathways and early detection and rapid response strategies of four IAS of different taxonomic groups: American pokeweed (*Phytolacca americana*), the gray squirrel (*Sciurus carolinensis*), the thousand canker disease associated with the fungus *Geosmithia morbida*, and the Emerald ash borer (*Agrilus planipennis*), they identified some of the challenges in early warning systems. Notably, they state that knowledge gaps in both species identification as well as in pathways of spread, insufficient resources, including scientific capacity, and public perception were hindrances to efficient actions against these IAS.

The European Food Safety Authority (EFSA) is an agency of the European Union (Pautasso, 2015). Although the plant health risk assessment by the EFSA pertains mostly to agricultural pests, there are panels dedicated to forest IAS, which produce scientific opinions, pest categorisations, and pest surveys regularly published in the EFSA Journal.<sup>6</sup>

The International Plant Sentinel Network (IPSN) specifically identifies insects, pathogens, and plants that have damaged non-native plants in an arboretum or botanical garden (International Plant Sentinel Network, 2022). The IPSN network targets IAS relevant to forests with a network of member botanic gardens and arboreta around the globe that share knowledge of new and emerging IAS risks observed in their gardens.

The initial search for papers specifically related to Central Asia conducted on Google Scholar and Scopus using the English-language terms was ineffective. In contrast, a targeted search of Russian-language literature from national journals, conference proceedings, and similar sources yielded positive results—retrieving 57 relevant articles that provided the necessary information for this study.

The annual national report on the phytosanitary state of the territory of the Russian Federation (including its Asian part), underlines that, as part of the EWEA system, regular monitoring (in particular pheromone trapping) is performed in the entry ports for early

2 <http://www.reufis.org/>

3 IPSN, <https://www.bgci.org/our-work/networks/ipsn/>

4 IPPC, <https://www.ippc.int/>

5 EPPO, <https://www.eppo.int/>

6 <https://efsa.onlinelibrary.wiley.com/journal/18314732>

detection and rapid action against newly arrived IAS that can potentially pose a danger to the forest sector of the country (National report..., 2021). Thanks to this program, only in 2020, 16 quarantine IAS (including those of North American origin) were documented, and the initial regulated areas were rapidly established for further phytosanitary measures (National report..., 2021).

As a part of the EWEA system, Dgebuadze et al. (2008) developed a database (so-called «A problem-oriented WEB-portal») on IAS in the Russian Federation.<sup>7</sup> This database includes information on selected actual and potential IAS in the country and provides information on various aspects of IAS, as well as data for modeling their further distribution. Kuznetsov and Storozhenko (2010) consider the Russian Far East, due to its rich tree and insect diversity, as a source of novel and emerging dangerous IAS that may spread across the country and penetrate to other territories, as seen in the recent example of the Emerald Ash Borer, *Agrilus planipennis* (Coleoptera: Buprestidae). In Russia, as a particular example of early action, Gninenko et al. (2017) considered the aggressive IAS from the Far East, the Ussuri bark beetle (also known as the Sakhalin fir bark beetle), *Polygraphus proximus* (Coleoptera: Curculionidae Scolytinae), a pest of coniferous trees (mainly firs) that has invaded some parts of Siberia and spread to European Russia, posing a danger to Europe EPPO A2 list. As an example of EWEA application, the Botanical Garden of the Russian Academy of Sciences in Moscow hosted the westernmost expansion of the beetle, which was promptly eradicated. Gninenko et al. (2017) emphasize that regular monitoring is crucial for the early detection of this IAS. Gabrid (2016) mentioned that in Kyrgyzstan, the main challenge is the early detection of novel IAS on non-native trees introduced into the country, i.e., both IAS that arrive from their native regions following the distribution of their host plants and the timely detection of native pests shifting from native plants to introduced non-native trees. Repukhova (2021) reported that in Karachay-Cherkessia (the North Caucasus region of Southern Russia), all possible measures are used (monitoring, visual inspections, active collaborations with the private sector) to detect IAS and immediately act against the invaders.

### 3.1.2 Sentinel plantings

For early detection of potential IAS, the use of non-native woody plants, which can serve as “live targets” for harmful species, was proposed for the first time by two research teams from New Zealand (Fagan et al., 2008) and North America (Britton et al., 2010). Since then, this concept has been improved (Eschen et al., 2019; Morales-Rodríguez et al., 2019; Vettraino et al., 2019) and has become an internationally recognized tactic for detecting potential IAS associated with international trade. Many IAS appearing in recent years were not previously recognized as pests before they had established themselves and disrupted their newly inhabited ecosystem (Roques et al., 2015; Barham et al., 2016; Carnegie and Nahrung, 2019), and some were unknown to science before they invaded new regions (Kirichenko et al., 2019). A Pest Risk Assessment (PRA) requires a species to be recognized as a pest before action can be taken; the possibility for unknown IAS to slip through biosecurity measures is inevitable (Barham, 2016; Morales-Rodríguez et al., 2019). Furthermore, it is difficult to detect IAS before physical symptoms are present on host

plants, at which point the invasion becomes far more difficult to eradicate (Wondafrash et al., 2021).

Botanical gardens, arboretums, as well as urban gardens (all three are hereby referred to generically as arboretums) and trees (Vettraino et al., 2017) are more susceptible to forest IAS due to the reduction of biodiversity in urban areas and other stresses from anthropogenic disturbance (Paap et al., 2017). This makes arboretums a crucial arena for IAS research. Arboretums often carry a range of native and non-native plant species within the same genus, which can be advantageous for studying novel pest-host associations (EPPO, 2020). The mature trees of arboretums, as opposed to the young seedlings of sentinel nurseries (Vettraino et al., 2017), are highly suitable for detecting woodborers and for subsequently tracking them (Eschen et al., 2019). Furthermore, woody plants of urban and peri-urban areas can also provide important information on possible bridgehead invasions, which is a common blind spot for sentinel plantations (Mansfield et al., 2019; Wondafrash et al., 2021). Arboretums are not without some hazards to biosecurity. Primarily, the trade and exchange of woody plants between arboretums means that they have historically posed an IAS risk themselves (Wondafrash et al., 2021). There is a need for the implementation of phytosanitary measures, such as inspections, and for IAS identification before accepting new plant specimens into arboretums, as some pests may not be visible (Morales-Rodríguez et al., 2019; Wondafrash et al., 2021).

There were many studies from this review that reinforced the efficacy of arboretums in an international sentinel network (Kirichenko et al., 2011; Hulbert et al., 2019; Kirichenko and Kenis, 2016; Kolyada et al., 2022; Morales-Rodríguez et al., 2021). Exploring the trophic associations of IAS in arboreta provides essential information for EWEA, especially when IAS are predicted to spread to new territories or have already been detected, expanding their secondary range. Several authors studied the trophic associations of severe Asian pests, *Agrilus planipennis* and the Ussuri bark beetle, *Polygraphus proximus* (both from Coleoptera), with introduced woody plants in the botanical garden in Moscow (Baranchikov et al., 2014; Mukhina et al., 2015; Baranchikov and Seraya, 2016). The potential hosts and their interactions with IAS are of high value for EWEA systems, and thus, opportunistic surveys of alien plants in the botanical gardens may help detect alien species infesting native trees (Grebennikov and Mukhanov, 2019).

An efficient sentinel network for EWEA requires communication and global cooperation among importers and exporters of plant material (Paap et al., 2017; Hulbert et al., 2019; EPPO, 2020). Such a network has been established by both the Botanical Garden Conservation International (BGCI) and the EUPHRESO project: International Plant Sentinel Network.<sup>8</sup> BGCI is a network of arboretums with over 100 member gardens from around the world, in operation since 1987.<sup>9</sup> IPSN aims to provide data on novel and emerging IAS, offering early warning of organisms that could pose a threat in the future (Barham, 2016). IPSN provides online resources to its member gardens, such as protocols, examples of best practice, comprehensive guides, and surveying tools, as well as general support for biosecurity and good practice in IAS identification, including links to databases, resources, and information from around the world (Barham et al., 2016). IPSN also works to raise awareness of plant health outside of its member gardens

<sup>7</sup> <http://www.sevin.ru/invasive/>

<sup>8</sup> IPSN; <http://www.plantsentinel.org/>

<sup>9</sup> <https://www.bgci.org/>

by speaking at conferences and meetings, and disseminating information via newsletters and social media (Barham et al., 2016). This support and organization at the global level is vital to the efficacy of the IPSN program. The main difference between IPSN and BGCI is that IPSN includes NPPOs and Regional Plant Protection Organizations (RPPOs) and plant health scientists, alongside the botanical gardens and arboretum, whereas BGCI members are botanic gardens, seed banks, or other botanical institutions (Barham, 2016).

### 3.1.3 Trapping and detection

It is well recognized that detection of IAS is most useful before establishment, and the cost of eradication increases once the pest is established, further increasing as it spreads (Nadel et al., 2012; Barham et al., 2016; de Groot et al., 2020). Pre-establishment detection, including pre-border and border trapping, involves lure traps for IAS (Santoiemma et al., 2024) as well as detection methods using visual inspections or molecular diagnostic tools (Morales-Rodríguez et al., 2019; Luchi et al., 2020).

In Russia (both European and Asian parts) and in Central Asia, as part of the EWEA system, pheromone monitoring and visual surveys are considered the main tools for early detection of IAS. Pheromone monitoring is more effective in early detection, as it allows intercepting of IAS at a very early stage of introduction, whereas visual surveys may fail to detect pests present at very low densities (Abasov et al., 2022). In Russia, most administrative regions (and especially the territories of high phytosanitary risk) are covered by pheromone monitoring as a part of the national EWEA for early detection of IAS. The number of pheromone traps used increased in the country by 40.5 times from 2009 to 2020, and the surveyed areas increased by 7 times, from 458.7 thousand hectares to 3191.8 thousand hectares for the same period (Abasov et al., 2022). As a result, a steady increase in the number of cases of detection of IAS has been reported: from 28 to 6,065 cases, i.e., 216 times, from 2009 to 2020. Notably, the main share of detection cases (62.5%) involves forest pests (Abasov et al., 2022).

The combined use of various means: visual survey, light, pheromone, and sticky traps has shown potential for early detection of IAS (Jioeva et al., 2014). However, visual surveys still remain the main approach for early detection of tree pests, especially in Asia. Conducting regular visual surveys of trees and shrubs in the Russian Far East allows IAS to be detected promptly (Dedyukhin and Titova, 2021; Mandelshtam et al., 2018).

Use of windfall trees as traps in the area where a windstorm occurred can help not only to monitor population dynamics of local pests but also to detect IAS. Examples from Kazakhstan of regular surveys after windfall have allowed the detection of IAS known as tree pests in their native ranges, e.g., *Acanthocinus griseus* (Coleoptera: Cerambycidae), *Dryocoetes autographus* (Coleoptera: Curculionidae), and *Sirex juvencus* (Hymenoptera: Siricidae) (Temreshev, 2015), as well as additional species later (Temreshev, 2017).

There are different tools that allow for the identification of emerging and intercepted IAS rapidly and reliably. For insects, DNA barcoding that uses a relatively short fragment of mitochondrial DNA (mtDNA) of the cytochrome oxidase I gene (COI; barcoding fragment 658 bp) is commonly utilized (Hebert et al., 2003). The advantage of this molecular genetic method is that it is applicable to any developmental stage, including immature stages (egg, larva, pupa), which are often morphologically unidentifiable. As discussed previously, DNA barcoding is used in sentinel planting surveys, where the pests are

usually detected in early developmental stages (Roques et al., 2015). Furthermore, this tool is utilized to identify IAS commonly intercepted at immature stages in entry ports, as, for instance, shown in the studies on plant health biosecurity by Armstrong and Ball (2005) in New Zealand, Hodgetts et al. (2016) in the UK, and Madden et al. (2019) in the USA. Although this method is highly promising for implementation in EWEA and biosecurity programs, it is not free of limitations, such as the time required to process samples and the relatively high cost for developing countries. Another limitation of using DNA barcoding for IAS identification is the lack of verified reference databases for all described species, as well as the presence of misidentifications in existing public genetic databases (Armstrong and Ball, 2005; Hodgetts et al., 2016; Roques et al., 2015), which is highly important for early detection (Morales-Rodríguez et al., 2019).

Molecular techniques based on polymerase chain reaction (PCR) and Loop-mediated isothermal amplification (LAMP) are generally more specific to IAS and much faster, making them advantageous for rapid detection and identification of IAS (Morales-Rodríguez et al., 2019; Rizzo et al., 2020). Successful LAMP assays have been developed for certain IAS such as *Anoplophora glabripennis*, *Aromia bungii*, *Ceratocystis platani*, *Phytophthora ramorum*, *Pityophthorus juglandis*, and *Xylella fastidiosa* (Aglietti et al., 2019; Rizzo et al., 2020). All of these LAMP assays were accurate in detecting the target species and demonstrated high specificity, although they require a considerable investment.

### 3.1.4 Pathways

Humans have undeniably aided the pathways of IAS not only by mediating their transport (i.e., trade and tourism), but also by creating factors that favor their establishment, such as homogenous plots of tree species or alterations of forest habitats for civilization (Panzavolta et al., 2021). Although the movement of IAS occurs naturally even over long distances, these movements have predictable ecological patterns, unlike the transport that occurs by human-mediated means (Panzavolta et al., 2021). Understanding the pathways of IAS is crucial for fostering efficient biosecurity measures. As the physical inspection of all plant products transported is impossible due to limited time and resources, the prioritization of high-risk commodities and their pathways enables more effective allocation of these resources (Eschen et al., 2017).

Live plants, being the main pathway of IAS into Europe, are followed by wood packaging, wood, and bark, produce (although this pathway is most applicable to agriculture, with some overlap in forest health), and lastly, soil (Panzavolta et al., 2021). One study found a positive correlation between the number of IAS in a country and the quantity of plants and woody products imported, which exemplifies the exacerbating effect that imported plant materials have on IAS establishment (Eschen et al., 2014). Plants imported to Europe from Asia and Africa, and wood packaging from Asia, have been highlighted as the most common pathways of IAS (Panzavolta et al., 2021). The main source of insects was identified as Asia, whereas fungal pathogens are more commonly originating from South America (Panzavolta et al., 2021).

Eschen et al. (2014) conducted a pest risk analysis of the likelihood of establishment and potential sources of IAS entering Europe from 344 regions. By identifying hierarchical clusters of organism groups, they were able to rank the risk of each cluster for a given European country. In addition, they also developed potential

organism risk groups for regions similar to countries in the EU. These risk groups may be used to inform importation inspections of woody plant products. Additional factors, such as trade relations and geographical distance, should be considered when prioritizing risky IAS. Eschen et al. (2017) describe a method for the use of risk filters to identify high-risk forest IAS and to inform commodity inspection regulations. The filter assessment reveals a risk categorization on certain woody plant commodities, guiding the appropriate allocation of resources. Using biological genus characteristics combined with the dynamics of the plant commodity (i.e., import volume, trade relationship history), they were able to determine the risk factor and corresponding phytosanitary measures for a given plant commodity.

There are a few studies examining IAS pathways in Central Asia. Orlova-Bienkowskaja (2017) compiled data on 168 alien beetle species from 30 families (more than half of which invaded European Russia during the last two centuries), allowing her to reveal the main trends of beetle invasions in European Russia. The author highlighted that the high percentage of new alien beetle species has been steadily increasing since the middle of the 20th century, reaching more than 50% in the recent 20 years, among which are *Agrilus planipennis*, *Anisandrus maiche*, *Trichoferus campestris*, *Xyleborinus attenuatus*, and *Xylosandrus germanus*.

### 3.1.5 Citizen science

Citizen science is the participation of the public in scientific studies, including visual surveys and monitoring of IAS. Citizen participation often advances research by generating new knowledge on IAS, as well as increasing awareness and emphasizing the need for early action against IAS. Employing voluntary citizen action in large numbers, aided by public awareness campaigns about forest IAS, could provide adequate coverage on the ground. Some of the citizen science programs presently in place in Europe include: Observatree<sup>10</sup> in the UK; LIFE ARTEMIS<sup>11</sup> in Slovenia; and EASIN,<sup>12</sup> an initiative of the European Commission. A project LIFE ARTEMIS carried out in Slovenia found that the majority of Slovenes expressed support for EWEA systems to combat IAS damaging Slovenia's forests (Japelj et al., 2019). EWEA includes monitoring the presence and abundance of IAS while informing the public about possible threats and engaging them in IAS removal. The following factors contribute to the success of anticipatory action systems, which depend on citizen engagement: citizens' pre-existing knowledge of IAS; demographic variables; environmental values; perceived threat from IAS; emotional factors; economic impacts; IAS biology/ecology; and communication by relevant organizations (Japelj et al., 2019).

A survey of public awareness of IAS across nine European countries found considerable variation in participant responses across the different regions (Eriksson et al., 2019). In general, they found that there is a high acceptance of stringent measures for plant production but low acceptance of restricting access to public areas (Eriksson et al., 2019). The survey also determined that although there is a low awareness of specific IAS, there is good general awareness of the problem. With this in mind, there is a high potential for the use of citizen science in EWEA systems for forest IAS.

Citizen science is a new area of research that has not been as well developed in Central Asia: we found no publications on the participation of the public in the detection of IAS and monitoring of their ranges. However, in 2021, two campaigns were initiated to involve the public in IAS research in Russia and Central Asian countries: one through social networks (Facebook and Instagram) and targeted mailings, and another one that, in addition to social networks, used a specialized website on citizen science in Russian-speaking countries.<sup>13</sup> The first study was dedicated to early detection and monitoring of the distribution of the horse chestnut leaf miner, *Cameraria ohridella* (Lepidoptera: Gracillariidae) (Kirichenko et al., 2021). The involvement of hundreds of citizens across 40+ regions allowed early detection of IAS in localities where it had not been previously recorded, enabling the specification of the secondary range, as well as the collection of specimens for genetic study (Kirichenko et al., 2021). The second study, an ongoing campaign, is on the brown marmorated stink bug (*Halyomorpha halys*), a pest of East Asian origin attacking over 100 species of plants, including many agricultural crops (Musolin, 2021).

Using citizen science for EWEA will be primarily directed at post-border IAS invasions, as it occurs within a nation's borders. This makes timely detection of the utmost importance. Employing voluntary citizen action in large numbers, aided by public awareness campaigns about forest IAS, could provide adequate coverage on the ground.

### 3.1.6 Modeling

Using models has become increasingly popular in forest management, particularly for early warning predictions, similar to models for forest fires, droughts, vegetation indices, and other environmental risks. Orozco-Fuentes et al. (2019) demonstrated the use of modeling to predict when a disease transitions from its onset to an outbreak in a forest environment by coupling early warning indicators with epiphytotic evidence. These modeling results are useful not only for predicting outbreaks but also for designing preventative interventions (Orozco-Fuentes et al., 2019).

Morozova and Borisov (2010) developed an open geo-information system (GIS) on IAS (mainly alien plants, including woody plants) of European Russia based on actual observations. This database includes information about species morphology, ecology, present distribution (i.e., primary and secondary ranges), and descriptions of pathways. They represented spatial data as geocoordinates (findings of species) with polygons (administrative districts) and used Google maps for cartography with layers (reflecting progressive distribution) generated by a cartographic server. Using the developed data system, the following problems can be resolved: automatic accumulation of data on alien species and their ranges, monitoring and modeling of their distribution across the whole territory of European Russia, taking into account species requirements and various environmental factors.

Perevaryukha (2018) dealt with the modeling of the distribution and population dynamics of alien species in ecosystems of Russia. He proposed a model based on lagging regulation for actual scenarios of population behavior in a new environment. Modeling of early warning signs in forest health has become a useful tool in the past decade, not

<sup>10</sup> <https://www.observatree.org.uk>

<sup>11</sup> <https://www.tujerodne-vrste.info/>

<sup>12</sup> <https://easin.jrc.ec.europa.eu/easin/CitizenScience/BecomeACitizen>

<sup>13</sup> <https://citizen-science.ru>

only for its predictive accuracy but also because of the accessibility of high-resolution satellite data via freely accessible programs such as the Copernicus Sentinel-2 mission.<sup>14</sup> Accessibility is a recurring theme in successful EWEA systems and is increasingly important in the case of modeling for forest management.

## 3.2 Survey

### 3.2.1 Short answer questions

Overall, the specialists from 22 countries from Central Asia and Europe participated in the survey (Figure 1; Supplementary File 2). Although the majority of the respondents originated from European countries (~77%), they were often represented by only one specialist per country. In Asia, the following countries responded: Armenia, Azerbaijan, Kazakhstan, Kyrgyzstan, Russia (Asian part), and Türkiye, with the majority of respondents in the Asian group coming from the Asian part of Russia (71% of Asian respondents).

The countries were then grouped into Western and Central Europe, Eastern Europe, and Central Asia, to represent macro-geographic regions, as shown in Figure 2.

A total of 96 participants responded to the survey (Figure 2). All macro-regions were relatively evenly represented in the survey: 31 respondents (32%) stated that they are based in Western and Central Europe, 27 (28%) from Eastern Europe (including the European part of Russia), and 38 (40%) from Central Asia (Central Asian countries and the Asian part of Russia).

The survey received respondents from all of the given age ranges; the range from 40 to 49 was the highest, with 42 respondents, nearly half of the total. The lowest number of respondents came from the range of 70 and over (~3%). In the case of this study's occupation demographic, there was a large bias toward researchers [66 respondents (69%)], followed by laboratory and department heads [17 respondents (18%)]. This is partly because awareness of EWEA systems falls mainly within academic occupations.

The results show that *early detection*, which was indicated in 34% of all responses, was strongly favored as a descriptor for EWEA systems. This is not surprising, given that the term *early* is in the descriptor. Second, there is the term *rapid response* (23% of all responses). *Rapid Response* is a common term used to describe systems that enable the detection and removal of IAS early enough to avoid harm to a forest ecosystem (de Groot et al., 2020), which makes it a good candidate for describing EWEA systems, as they share many of the same principles. *Public awareness* (7.1% of all responses) was least associated with EWEA systems, and only six respondents chose *other* to describe their perception of EWEA (Table 1).

Table 2 shows the number of times respondents referred to the options above as recognizable EWEA systems in the country where they are currently working. There was a fairly even spread between options: *Border or entry port trappings* [69 responses (36%)], *Citizen science* (51, i.e., 26%), and *Molecular diagnostic tools* [46 (24%)]. While *Sentinel trees* [19 responses (10%)] were the least chosen option other than *none*, it is surprising that *Sentinel trees* were the least selected, bearing in mind the number of papers our working group uncovered in the review of EWEA on the topic of sentinel trees for early warning against IAS systems (See Eschen et al., 2019; Kenis et al., 2018;

Wondafrash et al., 2021 as examples). In contrast, the number of articles on citizen science for EWEA systems was relatively limited.

The final question of the survey asked respondents to select all applicable IAS from the list seen in Table 3 that they consider a priority in their region or area. The top 3 IAS were one insect, one nematode, and one phytopathogenic fungus: *Agrilus planipennis*, *Bursaphelenchus xylophilus*, and *Hymenoscyphus fraxineus*, respectively. They received similar attention from the specialists and were mentioned in 42% of all responses. The other species deserving attention were three insect species, i.e., *Cydalima perspectalis*, *Ambrosia beetles*, *Corythucha ciliata*, and one phytopathogen, *Fusarium circinatum*; altogether, they were indicated in 38% of the replies. The invasive alien plants—three species in our list: *Heracleum mantegazzianum*, *Amorpha fruticosa*, *Impatiens balsamifera*—received the least attention by the specialists (altogether 11.5% of all replies).

Among other forest invasive alien species as a priority in the area or region of the survey participants, the most frequently listed, and thus preveived as most threatening, is the bark beetle *Polygraphus proximus* (27% of all replies in the option Other\*). It was followed by longhorn beetles, *Anoplophora* spp. (11.5%), followed by other insect species such as *Halyomorpha halys*, *Hyphantria cunea*, and *Psacotha hilaris* (altogether 23%) because of the large amount of damage they have caused in the regions they were accidentally introduced. According to the experts, insects appear to be the priority group while fungi, nematodes, and plants are perceived as less threatening.

The analysis of the selected priority IAS by macro-region provided a better understanding of why those IAS were selected. The respondents from Central Asia most often indicated that none of the listed species were considered a threat (i.e., 44% of all replies received from Central Asia). Moreover, the respondents from Central Asia frequently listed other species. The species listed in the questions were most often selected by respondents in Western and Central European countries (Figure 3). The pests of ash (*Fraxinus*) trees, i.e., *Agrilus planipennis* and *Hymenoscyphus fraxineus*, were the most selected by the respondents from Western and Central Europe and from Eastern Europe compared to Central Asia. This is explained by the fact that ash species are widely distributed in Europe, and these two IAS are currently threatening European ashes, whereas in Central Asia, *Fraxinus* plants have a disjunctive range and thus receive less attention than those in Europe, where ash is ecologically and economically important. Notably, the nematode *Bursaphelenchus xylophilus* was the species mentioned regularly by the specialists from all geographic regions (Figure 3). This can be justified by the presence of conifer forests across most of the studied regions and the potential for severe ecological and economic losses in the event of accidental introduction, as shown in the recent study by Kirichenko et al. (2021).

### 3.2.2 Long answer questions

The survey included two long-answer questions in which respondents were asked to justify the previous yes/no questions. The first question asked respondents to justify their response to: *If you are aware of early warning systems, do you consider them effective in detecting invasive alien species?* Of the 96 respondents, 38 (i.e., 40% of all survey participants) responded *yes* to this question and justified their answer with positive viewpoints on the effectiveness of EWEA systems in their region. Eighteen specialists (i.e., 19% of all respondents) responded *no* and justified their answer with negative viewpoints on the effectiveness of EWEA in their region. Nine respondents (9%)

<sup>14</sup> <https://sentinel.esa.int/web/sentinel/missions/sentinel-2>

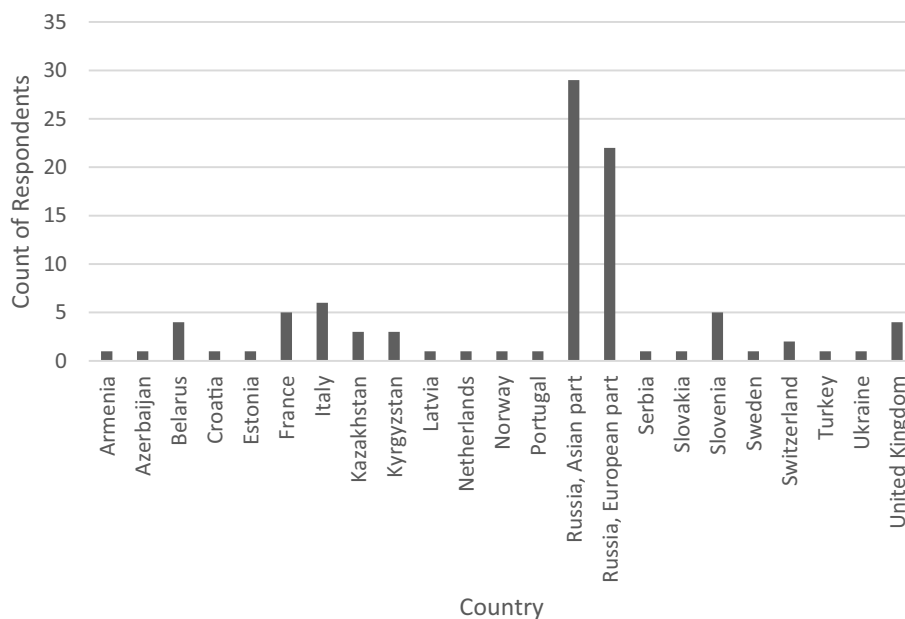


FIGURE 1  
Count of respondents by country.

justified their answers with a mix of negative and positive feedback on EWEA systems, of whom one had selected *no* to the previous question, and the rest had selected *yes*. There were also 31 responses that were either left blank or the response was not applicable. Of the 38 respondents who answered this question with positive viewpoints on the effectiveness of EWEA systems, 16 emphasized the importance of “timeliness” for a system to adequately respond to potential IAS invasions. Five of the respondents suggested that the effectiveness of an EWEA system relies on an “integrated approach,” which involves multiple levels of government and stakeholders, and two of the positive responses suggested that citizen involvement was an important aspect of the effectiveness of EWEA. The last 15 of the positive responses to this question varied greatly and were difficult to categorize. All answers can be viewed in [Appendix 2](#). The 18 respondents who answered with a negative viewpoint of the effectiveness of EWEA were grouped into three categories: technical setbacks, the ability of EWEA systems to act in time, and bureaucratic issues. Eight respondents suggested both technical and bureaucratic issues, and two respondents indicated that the issue with EWEA systems was that they were too slow to adequately respond to newly discovered IAS populations.

The second long-answer question from the survey was a justification response to the question: *Do you consider forest invasive alien species to be a threat to your job, livelihood, or health?* These justifications have been grouped as follows: responses indicating that IAS have a negative impact on one’s livelihood [35 (36%)]; responses indicating that IAS do not have a negative impact on one’s livelihood [15 (16%)]; responses with mixed answers [16 (17%)]; and those who left the question blank or whose answer was not applicable [22 (23%)]. The responses suggesting that IAS have a negative impact on one’s livelihood emphasized overarching themes on human health, ecosystem services, and biodiversity, which naturally have overlapping repercussions and were therefore not differentiated. Responses indicating that IAS do not have a negative effect on respondents’ livelihood were split between those whose jobs rely on IAS research and those who do not consider IAS as a serious threat. Many respondents who chose *no* explained in the follow-up question that IAS are not a threat to their

livelihood because their research depends on the continued presence of IAS. Of the 45 respondents who answered “No” to this question, 15 justified their answer by stating that their job depends on the presence of IAS. Of those 15, 11 reported their occupation as *Researcher*, 2 as *Laboratory/Department Head*, and 2 as *Forest Technician*. Other than the 15 respondents who stated that IAS research is vital to their livelihood, there were 30 other respondents who also selected *no*. Of those 30, 15 responses indicated that IAS is not (yet) viewed as a significant threat to the respondent’s livelihood, often relative to other threats, and the remaining 15 did not justify their answer.

### 3.3 Limitations

Despite our study providing a comprehensive overview of EWEA systems in Europe and Central Asia, there are several limitations that are important to highlight. First, our study was performed within a 2-year period (2021–2022) under the initiatives of the FAO; thus, this manuscript includes only literature from this time period and does not include the literature published in the following 3 years (2023–2025). We believe that in the following 3 years, new approaches in EWEA are unlikely to be developed, especially in Russian-speaking countries, bearing in mind the focus on geopolitical issues. Including the most recent Russian literature relevant to EWEA is unlikely to significantly alter the trends described in our overview.

Second, despite using the same initial approach for the search of EWEA literature in both Europe and Central Asia, i.e., using Scopus and Google Scholar, the results were significantly biased toward Europe. Furthermore, for Russian-speaking countries (mostly Central Asian countries), we performed an additional search in the Russian language (because we did not succeed in finding a representative number of papers on Scopus and Google Scholar on Central Asia that were published in English). However, we did not perform searches in the national languages of European countries. This may have led to the overlooking of strategies and novelties of EWEA systems at a national level.

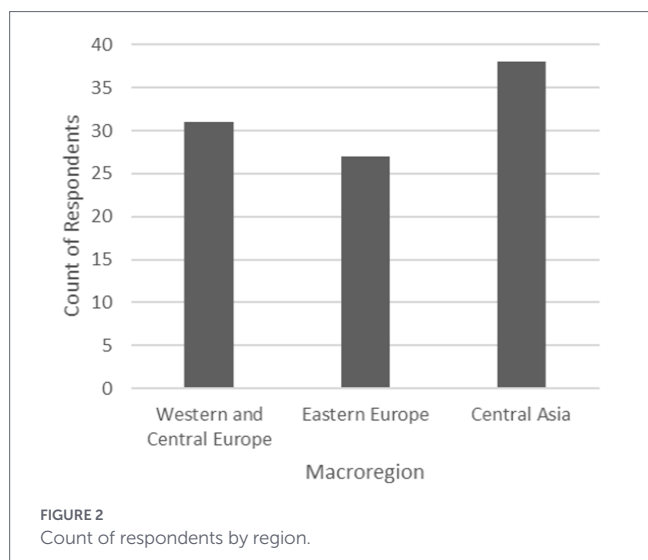


FIGURE 2 Count of respondents by region.

TABLE 1 Count of responses to the question: Do you recognize the term Early Warning Early Action (EWEA) within your industry/region? If you selected "Yes" to the previous question, which of the following most closely resembles your understanding of this term?

Options	Count
Early detection	53
Rapid response	35
Preventive measures	26
Biosecurity	24
Public awareness	11
Other	6
Total	155

TABLE 2 Count of responses to the question: Of the following EWEA systems, click all that you recognize from the country you are working in.

Options	Count
Border or Entry port trappings	69
Citizen science	51
Molecular diagnostic tools	46
Sentinel trees and plantings	19
None	8
Total	193

Finally, in the EWEA survey, there was a bias toward Europe, with 58 respondents from European countries vs. 38 respondents in Central Asia. This could potentially affect specific results. However, because we did not aim to compare EWEA systems between Europe and Central Asia, the results reflect the characteristics of the regions in terms of via IAS composition and survey findings, so the differences in respondent numbers did not significantly impact the conclusions drawn in the manuscript. Furthermore, the survey participants were mostly researchers and plant protection specialists, whereas other categories, particularly practitioners (i.e., foresters), were underrepresented. This should be kept in mind when interpreting the results of our study, especially regarding awareness of IAS importance and EWEA systems.

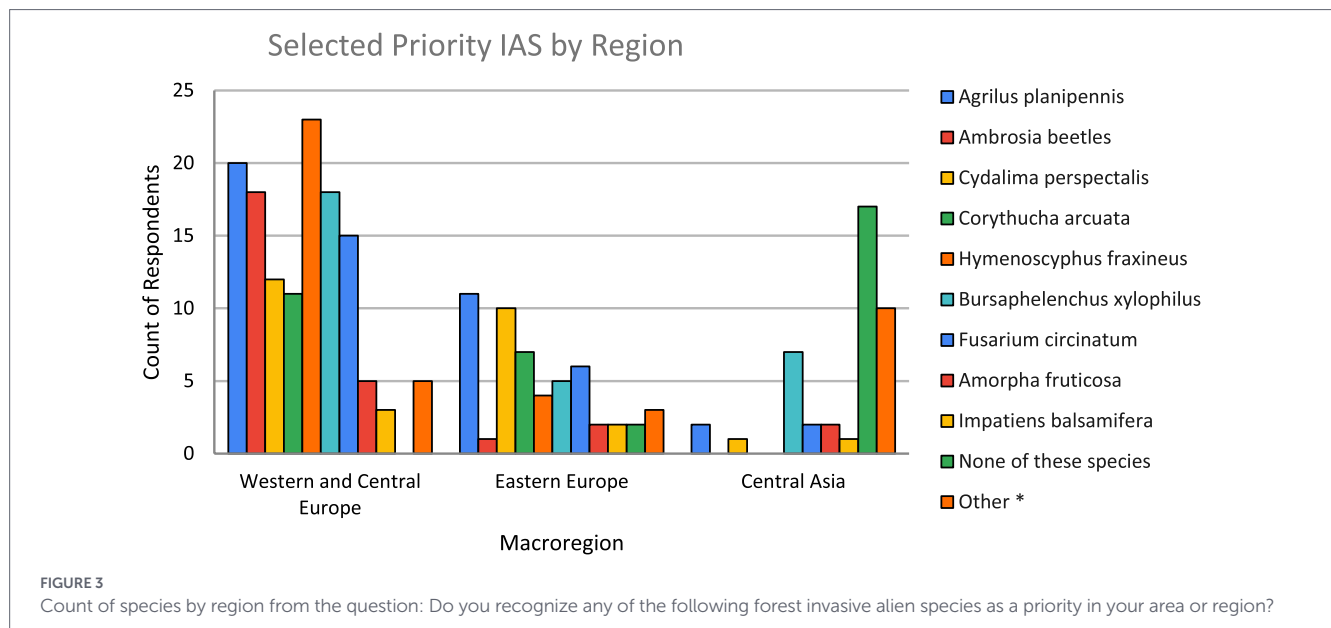
TABLE 3 Count of species selected from the question: Do you recognize any of the following forest invasive alien species as a priority in your area or region? Select all that apply.

Options	Count
<i>Agrilus planipennis</i>	33
<i>Bursaphelenchus xylophilus</i>	30
<i>Hymenoscyphus fraxineus</i>	27
<i>Cydalima perspectalis</i>	23
<i>Fusarium circinatum</i>	23
Ambrosia beetles	19
<i>Corythucha arcuata</i>	18
<i>Heracleum mantegazzianum</i>	10
<i>Amorpha fruticosa</i>	9
<i>Impatiens balsamifera</i>	6
Other*	18
None of these species	19
Total	216

## 4 Conclusion

### 4.1 Summary points

- The EWEA system is generally recognized as an optimal approach to contain the threats posed by IAS in various types of ecosystems. This result is confirmed by both the desk review and a survey that involved 96 experts, among researchers and plant health experts from Europe and Central Asia.
- Europe and Central Asia represent special cases for EWEA application due to their geographic nature: continuous landmass with Asia on one side and numerous entry points for commodities on the other.
- Forestry has paid less attention than agriculture to the deployment of EWEA systems, likely because of the lower economic value of the forest products, while not valuing the ecosystem services appropriately.
- There is high uncertainty about the grading of IAS importance by experts because of the different economic and geographic conditions of the macro-regions selected in the survey, and the often-uncertain link between experts and forest managers.
- Research seems to be more concerned than forestry by IAS and the application of the EWEA systems, indicating that the area is still under development, and it needs to be disseminated to a larger extent, especially to forest stakeholders.
- Increasing awareness of IAS threats in forests and society at large is prompting the deployment of EWEA in forest ecosystems.
- Trapping and detection at ports of entry of the commodities is seen as the most promising tool to achieve early detection and enable early action protocols, especially when supported by molecular tools.
- Target species of IAS vary according to the macro-regions based on the relevance of the host plants and trade patterns, suggesting a need to tailor specific measures according to the local conditions and forest stakeholders.
- Funding and central organization of the actions are seen as major limiting factors to the deployment of EWEA systems in Europe and Central Asia.
- Cooperation in developing common protocols is an essential step in achieving the targets, and this is a task addressed by FAO and EPPO.



## 4.2 Future issues

- Need for a regulatory approach for EWEA systems in national and international organizations, addressing the recommendations of organizations such as FAO and EPPO.
- Identification of IAS introduction hotspots for the focused application of EWEA systems, based on existing databases (e.g., EPPO Reporting Service, EASIN).
- Development of EWEA systems for key IAS in Europe in accordance with the EU legislation and that of the Central Asian countries.
- Intensifying the information flow to forest stakeholders and the general public to raise awareness of the systems and to encourage citizen collaboration at various levels (schools, stakeholders' organizations, industry).
- Integration of advanced technologies into the EWEA systems, while ensuring accessibility and data sharing.

## Data availability statement

The original contributions presented in the study are included in the article/[Supplementary material](#), further inquiries can be directed to the corresponding author/s.

## Ethics statement

The manuscript presents research on animals that do not require ethical approval for their study.

## Author contributions

DF: Writing – review & editing, Writing – original draft. NK: Writing – original draft, Writing – review & editing. AB:

Writing – review & editing, Writing – original draft. SS: Writing – original draft, Writing – review & editing.

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## Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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## Supplementary material

The Supplementary material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/ffgc.2026.1795394/full#supplementary-material>

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