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ORIGINAL ARTICLE

The utilization of biological control against regulated pests in the EPPO region: challenges and opportunities

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Abstract

Biological control is a pest control method that can offer an environmentally safer alternative to chemical pesticides. The proven safety record of both augmentative and classical biological control technologies allows its utilization against indigenous and non-indigenous but well-established pests, whether under protected conditions (e.g., glasshouses) or in open field cropping systems. This manuscript has been developed by the Joint European and Mediterranean Plant Protection Organization (EPPO) and the International Organization for Biological and Integrated Control (IOBC) Panel on Biological Control Agents and presents an assessment on the current use of classical and augmentative biological control for the control of regulated plant pests. The paper discusses challenges for the uptake of biological control for regulated pests and provides recommendations to increase the safe use of biological control agents in the EPPO region.

KEYWORDS
augmentative biological control, awareness raising, classical biological control, invertebrate pests, regional guidance, regulation

L'utilisation de la lutte biologique contre les organismes nuisibles réglementés dans la région de l'OEPP : défis et opportunités

La lutte biologique est une méthode de lutte contre les organismes nuisibles qui peut offrir une meilleure alternative pour l'environnement que les pesticides chimiques. La sécurité des technologies de lutte biologique augmentatives et classiques a été démontrée, et cela permet leur utilisation contre les organismes nuisibles bien établis (indigènes et non indigènes), dans des conditions protégées (par exemple, en serres) ou dans des systèmes de culture en plein air. Ce manuscrit a été élaboré par le Panel sur les agents de lutte biologique conjoint entre l'Organisation Européenne et méditerranéenne pour la Protection des Plantes (OEPP) et l'Organisation Internationale pour la Lutte Biologique (OILB) et présente une évaluation de l'utilisation actuelle de la lutte biologique classique et augmentative contre les organismes nuisibles aux plantes qui sont réglementés. Cet article aborde les défis du recours à la lutte biologique contre les organismes nuisibles réglementés et fournit des recommandations pour accroître l'utilisation en sécurité des agents de lutte biologique dans la région de l'OEPP.

Применение биологических мер борьбы с регулируемыми вредными организмами в регионе ЕОКЗР: вызовы и возможности

Биологическая защита растений является комплексом методов борьбы с вредными организмами, которые способны предложить более безопасную альтернативу по сравнению с использованием химических пестицидов. Доказанные примеры безопасного применения технологий массового выпуска агентов биометода и классической биологической борьбы позволяют применять их против местных и чужеродных успешно акклиматизированных вредных организмов, и делать это как в защищенных условия (например, в теплицах), так и в системах открытого земледелия. Данная статья подготовлена Совместной рабочей группой по агентам биологической борьбы Европейской и Средиземноморской организацией по карантину и защите растений (ЕОКЗР) и Международной организации по биологической борьбе с вредными животными и растениями (МОББ). В ней представлена оценка современного применения классических методов биологической борьбы и технологий массового выпуска агентов биометода для борьбы с регулируемыми вредными для растений организмами. В статье рассматриваются проблемы внедрения биологической защиты растений от регулируемых вредных организмов и даются рекомендации по повышению безопасного использования агентов биологической борьбы в регионе ЕОКЗР.

1 | INTRODUCTION

The introduction and spread of plant pests such as fungi, bacteria, viruses and invertebrates into new regions threatens plant health and food security (Mwangi et al., 2023; Riegler, 2018). We need to produce enough food to sustain the increasing global population, both now and into the future, therefore measures to mitigate and control pest species before they have an economic impact on crops are paramount. Historically, the control of pests has relied heavily on the application of chemical synthetic pesticides (van Lenteren, 2000). More recently, as concerns have grown over their negative effects, consumer demand has swayed away from their use. This is echoed and engrained into regional policy, which is driven by societal and environmental safety [e.g., the European Green Deal and the Farm to Fork strategy (European Commission, 2024; European Union, 2020), EU biodiversity strategy for 2030 (European Commission, 2020)].

The demand for a reduction in chemical pesticides begets novel, pragmatic and environmentally friendly approaches to pest control. Biological control is one such approach. It is defined as the exploitation of living agents (including viruses) to combat pests (including pathogens, invertebrates and weeds) for diverse purposes to provide human benefits (Stenberg et al., 2021). Thus, biological control agents (BCAs) include viruses, microorganisms (microbial pesticides) and invertebrates, such as entomopathogenic nematodes, predatory, parasitic and herbivorous arthropods and mites (macrobials). These organisms can be used to control plant pests (including invertebrates and microorganisms) and invasive alien plants, although the latter is not covered comprehensively in this paper.

There are three types of applied biological control practices (Mason, 2021 and chapters within). Classical biological control (or importation biological control) can be defined as the utilization of a non-native natural enemy that shares a co-evolutionary history with the non-native target pest or with a closely related species, and is introduced for permanent establishment and long-term control of the pest. This method is mostly applied against invasive plant pests and invasive alien plants that may have become too widespread for the effective use of alternative control methods, such as phytosanitary measures, cultural or chemical control. Augmentative biological control can be defined as periodic and systematic release of mass-produced BCAs (either indigenous or non-indigenous), and these are often produced commercially. Augmentative biological control can be further subdivided into seasonal inoculation, in which BCAs can reproduce and persist throughout the growing season, and inundation, in which BCAs cannot reproduce and must be frequently reapplied throughout the growing season. These BCAs can be applied within protected conditions as well as outdoors in cropping systems. Conservation biological control is the practice of manipulating the environment or habitat to promote beneficial organisms. Conservation biological control is practiced extensively throughout the European and Mediterranean Plant Protection Organization (EPPO) region, for instance with the establishment of field margins planted with plants or cover crops to attract and support natural enemies or in protected crops by, for example, providing supplementary diets or shelters for BCAs (Castella et al., 2022; Van Emedn, 1974).

In some areas, the fact that biological control can offer an environmentally safer alternative to chemical pesticides has led to certain BCAs wholly replacing chemical pesticides and in other cases to a significant reduction in chemical application (Calvo et al., 2012; van Lenteren, 2000). Usually, the aim of biological control is to suppress the target pest population to an economically acceptable damage level or below. However, some BCAs can also be used for the control of pests, for example *Encarsia formosa* Gahan (Hymenoptera: Aphelinidae) is sometimes recommended to eradicate *Bemisia tabaci* Gennadius (Hemiptera: Aleyrodidae) from greenhouses in situations where pesticides cannot be used, such as in butterfly houses (M. Everatt, personal communication).

Biological control methods are most commonly used against well-established pests, whether under protected conditions or in open field conditions, either within a crop or the natural environment. For regulated pests [defined as a quarantine pest or a regulated non-quarantine pest (RNQP) (ISPM 5; IPPC, 2023)], classical biological control has historically been applied when the pest is too widespread for traditional control techniques to be effective. However, more novel approaches are being explored where, for example, pre-emptive biological control of regulated A1 pests (EPPO A1 pests absent from the region) is receiving increased attention (Avila et al., 2023; Kenis et al., 2024; Kumar et al., 2020). Additionally, biological control of pests with a restricted distribution (e.g., EPPO A2 pests) can be implemented as part of integrated pest management (IPM) to halt or slow spread and reduce impact (e.g., Gotta et al., 2023; Pérez-Rodríguez et al., 2019).

The European and Mediterranean Plant Protection Organization has worked on BCAs since 1997. In 2008, EPPO and the International Organization for Biological and Integrated Control (IOBC) formed the Joint EPPO/IOBC Panel on Biological Control Agents with the remit to work on the assessment and regulation of the import and release of BCAs agents in plant protection. The Joint Panel has developed Standards in the PM 6 series: Safe use of biological control (see Section 3.2). These Standards cover a range of biological control practices, from the first import of a BCA for research purposes to conducting an environmental risk assessment with the potential for release. The Joint EPPO/IOBC Panel on Biological Control Agents focuses its work mainly on invertebrate BCAs implemented against invertebrate pests, and as such, this manuscript mainly provides and discusses examples within this context.

This manuscript discusses challenges for the uptake of biological control for regulated pests and provides recommendations to increase the safe use of BCAs in the EPPO region. Examples of regulated pests given in the paper may be recommended for regulation by EPPO (A1 or A2 pests), regional regulated pests (e.g., EU) or pests regulated by specific EPPO countries. For further details on pest categorization see EPPO (2024a).

2 | USE OF BCAS AGAINST REGULATED PESTS

Biological control can be applied against RNQPs, with the aim to reduce the level of pest presence below a threshold to allow movement of plants for planting (ISPM 16: IPPC, 2021; ISPM 21: IPPC, 2004). Biological control can also be applied to regulated pests under a systems approach (ISPM 14: IPPC, 2019), where countries put into place two or more measures to control a pest to allow trade of a commodity to another country. The measures include pre- and post-harvest measures. Biological control can be used to maintain a Pest Free Area (PFA) (ISPM 4: IPPC, 2017) and Areas of Low Pest Prevalence (AoLPP) (ISPM 22: IPPC, 2016). In the former, biological control could be used in the buffer zone of a PFA, while for the latter, biological control can be used in an AoLPP to suppress a pest population to below a threshold.

Certain situations may warrant the use of biological control for the control of regulated pests instead of chemical pesticides, for example in butterfly houses, post-entry plant quarantine stations, public areas, organic farming and certain habitats within the natural environment (e.g., on or near water bodies).

2.1 | Classical biological control

Classical biological control of insects has been repeatedly shown to be a successful management practice since the successful release of the ladybird *Rodolia cardinalis* (Mulsant) (Coleoptera: Coccinellidae) against *Icerya purchasi* Maskell (Hemiptera: Margarodidae) in citrus orchards in California, USA in 1888–89. In Europe, there have been approximately 650 releases of classical BCAs, with around 130 of these releases significantly impacting the target pest (Castella et al., 2022).

Examples of successes in classical biological control in Europe include, among others, the control of the chestnut gall wasp [*Dryocosmus kuriphilus* Yasumatsu (Hymenoptera: Cynipidae) using *Torymus sinensis* Kamijo (Hymenoptera: Torymidae)] (see Appendix 1), control of the woolly whitefly [*Aleurothrixus floccosus* Maskell (Hemiptera: Aleyrodidae)] using *Amitus spiniferus* (Brethes) (Hymenoptera: Platygastridae) and *Cales noacki* (Howard) (Hymenptera: Aphelinidae), control of San Jose scale [*Comstockaspis perniciosa* (Comstock) (Hemiptera: Diaspididae)] using *Encarsia perniciosi* (Tower) (Hymenoptera: Aphelinidae), control of the citrus leafminer [*Phyllocnistis citrella* Stainton (Lepidoptera: Gracillariidae)] using *Citrostichus phyllocnistoides* Narayanan (Hymenoptera: Eulophidae), control of the eucalyptus psyllid (*Ctenarytaina eucalypti* Maskell (Hemiptera: Psyllidae) using *Psyllaephagus pilosus* (Hymenoptera: Encyrtidae, classical BCA PM 6/3) and control of the cottony cushion scale (*Icerya purchasi*) using *R. cardinalis* (Gerber & Schaffner, 2016).

Classical biological control against invasive weeds in Europe has shown an increase in recent years with the release of *Aphalara itadori* Shinji (Hemiptera: Aphalaridae) against *Reynoutria japonica* (Polygonaceae), *Aculus crassulae* Knihinicki & Petanović (Acarida: Eriophyidae) against

Crassula helmsii (Crassulaceae), *Listronotus elongatus* (Hustache) (Coleoptera: Curculionidae) against *Hydrocotyle ranunculoides* (Araliaceae), *Puccinia komarovii* var. *glanduliferae* Tanner, Ellison, Evans & Kiss (Pucciniales: Puccinia) against *Impatiens glandulifera* (Balsaminaceae) and *Trichilogaster acaciaelongifoliae* Froggatt (Hymenoptera: Pteromalidae) against *Acacia longifolia* (Fabaceae). Globally, classical biological control against invasive plants has achieved a good rate of success, with over a quarter of biocontrol programmes resulting in complete control (where no other control methods are needed to suppress the target species) and 50–70% achieving partial control (resulting in a substantial reduction of other control methods) (Hinz et al., 2020).

Historically, classical biological control has been criticized for its potential negative impact on native biodiversity, which has occurred very occasionally (De Clercq et al., 2011; Palevsky et al., 2012; Rondoni et al., 2020; van Lenteren et al., 2006). However, nowadays the selection of non-indigenous natural enemies to be released as a classical biological control is more rigorous, and studies on the specificity of BCAs have become common practice, which strongly reduces the risks of non-target impacts (Hajek et al., 2016; Kenis et al., 2017). Host specificity testing is a requirement of many countries' regulatory systems. Most classical biological control programmes now also comply with Nagoya Protocol and access and benefit sharing agreements (Leskien, 2023; Silvestri & Mason, 2023).

Classical biological control does not aim to eradicate a pest, but rather bring its population density below an appropriate ecological or economic threshold. It is applied at the transitional phase between a quarantine pest status and deregulation. Often, host plant destruction and chemical control are preferred when attempting to eradicate a new outbreak of a regulated pest (Branco et al., 2023). When classical biological control is applied early in the invasion process, it can potentially be very efficient to slow the spread of the invasive species under containment strategies. However, classical biological control is often implemented late in the invasion process against well-established invasive species, when other control methods are not successful or not sustainable and represent high risks for human health and the environment. To be efficient against regulated pests, classical biological control programmes should be conducted as soon as a pest arrives into a new region. However, implementing a classical biological control programme requires significant funding and infrastructure (quarantine facilities), specialized scientific personnel and time to develop both in terms of administration (e.g., issuing permits) and scientific investigation (foreign exploration, clearance from safety tests, application and evaluation). Classical biological control is generally undertaken by public or not-for-profit agencies and applied non-commercially, as a public good.

The steps of a classical biological control programme include, among others, assessments of similar programmes implemented elsewhere against the same pest, surveys for natural enemies in the area of origin of the pest and studies of their biology and ecology, importation of natural enemies into quarantine laboratories, assessments of their potential non-target effects in the area of introduction, application for release, field releases and post-release studies (FAO, 2019). The whole process up until the field release can take between 3 and 10 years depending on whether efficient and safe natural enemies are already known at the beginning of the process, but also on various other factors (e.g., ease of rearing the pest and natural enemies in the laboratory, number of generations per year).

To allow a BCA to be released at the same time or just after an outbreak of a regulated pest, the concept of pre-emptive classical biological control has been developed (Avila et al., 2023; Hoddle, 2023). This process implies that risk and impact assessments are carried out for natural enemies in advance of the arrival of a pest. It may also mean that the BCA is approved for release prior to the pest arriving. Pre-emptive biological control has already been applied for the egg parasitoid *Trissolcus japonicus* (Ashmead) (Hymenoptera: Scelionidae), which has been approved for release in New Zealand to control the brown marmorated stink bug (*Halyomorpha halys*) should it arrive in the country (Charles et al., 2019). Avila et al. (2023) provides guidelines and a decision framework that can be used to assess the feasibility of conducting pre-emptive risk assessment for candidate BCAs.

In the EPPO region, a pre-emptive biological control approach could be considered for all arthropod pests of the EPPO A1 List, but also priority pests on the EPPO A2 List. Countries where the pest is not present could start a classical biological control programme pre-emptively in collaboration with countries where the pest is present. A previous Euphresco project (Preparedness in biological control of priority biosecurity) has produced fact sheets for 30 regulated pests in the EU or Oceania, describing current or past classical biological control efforts and suitable natural enemies for classical biological control against these pests. These fact sheets, available at the project website (https://biologicalcontrol.eu/), can be used to identify the most promising BCAs.

2.2 | Augmentative biological control

Augmentative biological control has been applied successfully in various agricultural systems from citrus orchards in the Mediterranean (Jacas & Urbaneja, 2010) to the control of vegetable pests in large-scale production facilities in Northern Europe for over 100 years (van Lenteren, 2012). It is estimated that over 350 species of natural enemies have been utilized for augmentative biological control against plant pests worldwide (Van Lenteren et al., 2018).

In recent decades, advances have been made in the mass production, storage and methods for delivery and application of BCAs that have led to products becoming more widely available (van Lenteren, 2012). Nowadays, Europe is the largest commercial market for invertebrate BCAs (Van Lenteren et al., 2018).

Augmentative biological control is applied against regulated and non-regulated pests, and as well as invertebrates, microbial BCAs are used. For example, the bacterium *Bacillus thuringiensis* is commonly used to eradicate new outbreaks of gypsy moth [*Lymantria dispar* L (Lepidoptera: Erebidae)] and Asian gypsy moth (*L. dispar asiatica* Vnukovskij) in North America and has also been used for the eradication of the painted apple moth [*Teia anartoides* Walker (Lepidoptera: Erebidae)] in the United States (Liebhold & Kean, 2019). Parasitoids and predators are almost never used in eradication programmes because they are not sufficiently efficient to kill all their hosts or prey. However, they may be utilized in very specific cases where chemical insecticides cannot be applied (e.g., against regulated pests in butterfly houses or when several pests need to be controlled at the same time, e.g., in post-entry plant quarantine stations).

As for classical biological control, pre-emptive biological control can be carried out for microbial and macrobial augmentative BCAs against a regulated pest that is not yet in a country or a continent. For example, Kenis et al. (2024) tested three European *Trichogramma* Westwood species to assess which one would be the most efficient against the fall armyworm [*Spodoptera frugiperda* (Smith) (Lepidoptera: Noctuidae)] in Europe. When efficient augmentative BCAs are known from the area of origin of the pest or from already invaded areas, those may be assessed for performance and safety in other (EPPO) countries. If safe indigenous or non-indigenous BCAs are found, the registration procedure could then be started before the arrival of the regulated pests (Babendreier et al., 2022).

3 | CHALLENGES

There remain a number of challenges to achieve a higher utilization of biological control against regulated pests in the EPPO region. The Joint EPPO/IOBC Panel on BCAs identified a number of these during the Joint EPPO/COST SMARTER Workshop on the evaluation and regulation of the use of BCAs in the EPPO region, which was held in Budapest in 2015 (EPPO, 2015; Ward, 2016). Still, some of these challenges remain and key ones are detailed in the following sections.

3.1 | Regulation

Augmentative invertebrate BCAs straddle a number of different regulatory categories (Ward, 2016). Invertebrate BCAs are not covered by EU regulation. They are not relevant for consideration under Regulation 1107/2009, which regulates pesticides and the placement of such products on the market because this is only relevant for micro-organisms and viruses. Although BCAs can fall under other regulations [e.g., Regulation (EU) 1143/2014 on the prevention and management of the introduction and spread of invasive alien species and Regulation (EU) 2016/2031 on protective measures against pests of plants], these are not specific for their utilization as a BCA, but if the organism is to be assessed as a plant pest (Castella et al. 2022).

The same is true for classical BCAs where their release can be restricted by environmental regulations, and plant health regulations provide no provisions except to ensure, through pest risk analysis, that the organism is not a pest to plants (IPPC, 2005).

Regarding national legislation, detailed information for all EPPO countries is lacking. For the EU Member States, Castella et al. (2022) detailed that 15 Member States have introduced specific provisions in their national legislation regarding invertebrate BCAs, three countries were developing regulatory provisions (at the national or regional level) and nine countries did not have any specific process to accommodate the use of invertebrate BCAs. These differences can hinder the uptake of BCAs and restrict their effectiveness of regional biological control programmes (Barratt et al., 2021; Mason et al., 2017).

EPPO provides a framework for the safe use of BCAs in the EPPO region. The EPPO Standard PM 6/3 (5) biological control agents safely used in the EPPO region (EPPO, 2021) provides a list of BCAs which are used in the EPPO region with no adverse effects or with acceptable adverse effects. In essence, this list (Appendix 1 Commercially or officially used BCAs and Appendix 2 Classical BCAs successfully established in the EPPO region) constitutes a 'positive' list of BCAs for the EPPO region. Member countries may consider adopting a simplified notification procedure for these BCAs (EPPO, 2021).

3.2 | Guidance

A lack of guidance and information on all aspects of biological control can hinder its uptake and hamper harmonization. This can lead to different methods being adopted between countries and can lead to a reduction in efficiency and quality of delivery. For the EPPO region, the EPPO PM 6 Standards on safe use of biological control provide a comprehensive set of guidance documents (see below) that can be used from the first import of a BCA to evaluating an application for release. Further guidance can be developed on specific technical aspects.

3.2.1 | EPPO PM 6 Standards

EPPO PM 6 series: Safe use of biological control

- PM 6/1 (2) First import of non-indigenous biological control agents for research under confined conditions (EPPO, 2023b).
- PM 6/2 (4) Import and release of non-indigenous biological control agents (EPPO, 2025).
- PM 6/3 (5) Biological control agents safely used in the EPPO region (EPPO, 2022).
- PM 6/4 (1) Decision-support scheme for import and release of biological control agents of plant pests (EPPO, 2018).
- PM 6/5 (1) Host specificity testing of non-indigenous (classical) biological control agents used against invasive alien plants (EPPO, 2023c).

3.3 | Information

A paucity of information can lead to a lack of understanding by stakeholders and hinder the uptake of biological control (Collatz et al., 2021). Castella et al. (2022) highlighted that farmers often do not have sufficient knowledge on invertebrate BCAs and their potential benefits, which can lead to a lack of uptake. Basic information on the methods used to determine the safety and efficiency of a BCA is often lacking in popular information disseminated to stakeholders (Catton, 2021). This can lead to scepticism in the way biological control practitioners select BCAs and a general perception of distrust.

3.4 | Awareness raising of biological control safety between all national bodies

Biological control has a well-established safety record (Barratt et al., 2018). However, there remains some apprehension to adopt biological control techniques due to perceived uncertainty as to the safety of the method. It is beyond the scope of this current paper to critically discuss this specific aspect in detail, but it is evident that a clear message on the benefits and successes in modern day biological control programmes should be disseminated to all interested national bodies.

4 | RECOMMENDATIONS

The Joint EPPO/IOBC Panel on Biological Control Agents has produced a number of recommendations that can promote and strengthen the utilization of biological control in the EPPO region. These are listed below, in no particular order.

4.1 | Information dissemination

Information dissemination acts to share knowledge on biological control from risk assessments, educational material, information fact sheets and species-specific information along with successful case studies. Technology transfer can facilitate the uptake of biological control in countries and regions where the method has a low rate of adoption and at the same time strengthen regional cooperation. Information needs for different stakeholders implies the necessity to produce information in different formats. For example, risk assessors and risk managers may require different information formats compared to farmers, managers and the general public. Information should include current case studies in addition to detailing historic examples. Information also needs to be readily available, preferably on a dedicated platform. This was highlighted in the 2022 EU Study on invertebrate BCAs (Castella et al., 2022) and it is a concept that EPPO is exploring.

Information deriving from risk assessment of non-indigenous BCAs should be available in a suitable format to be disseminated to stakeholders along with a clear presentation of the risk/benefits of releasing a BCA. For instance, Defra in the United Kingdom asked stakeholders for their views on the potential release of *Torymus sinensis* (Kamijo) (Hymenoptera: Torymidae) into England to suppress populations of *Dryocosmus kuriphilus* (oriental chestnut gall wasp) by presenting them with the full risk analysis report (Defra, 2020). The documented efficacy of this parasitoid, at least in some countries has led to multiple requests for releases (e.g., by chestnut growers, timber producers and natural forest managers), despite the ability of the parasitoid to move naturally over distances and across country boundaries (Matošević et al., 2017; Nieves-Aldrey et al., 2019). This highlights the need to explain scientific evidence in the context of the expectations of stakeholders. It also highlights that some stakeholders are the ones who push for the implementation of biological control.

Information will facilitate better decision making when it comes to assessing BCA applications.

4.2 | Awareness raising

Public interest and engagement for biological control of invasive pests can be more pronounced in situations where pests create significant social and economic impacts for residents in urban and peri-urban neighbourhoods, such as the case of the emerald ash borer *Agrilus planipennis* Fairmaire (Coleoptera: Buprestidae), which causes significant tree mortality and involves a wide variety of stakeholders from the private and public sector. In Europe the native parasitoid *Spathius polonicus* Niezabitowski (Hymenoptera:

Braconidae) may be a suitable BCA for *A. planipennis* and its potential for mass rearing and augmentative release programmes is currently being examined (Evans et al., 2020). However, experience shows that stakeholders might have a mixed perception of the advantage of using biological control for *A. planipennis*. On the one hand, parasitoids may not act quickly enough to reduce tree mortality in the short term, but on the other hand biological control can be viewed as an engagement tool with 'officials being seen to take action' (Marzano et al., 2020). In the latter situation it should be communicated that the parasitoids will not save infested trees but will reduce the population and slow the spread. Even more, acceptance of biological control can be easier when alternative approaches such as pre-emptive felling of trees is also a measure. This can have low support among the general public due to the change of neighbourhood aesthetics and also over uncertainties of the cost of felling and replacement of trees.

The public should be informed about the threat regulated species can cause to plant health and the natural environment, and agricultural commodities and the conditions under which biological control can be the appropriate strategy. The public should also be made aware that government agencies follow all regulatory rules to safeguard public interest and therefore enhance public trust (Warner & Kinslow, 2013).

The participation of stakeholders in online forums and expert working groups can support the regulatory underpinnings of using BCAs. This is the case for using exotic generalist arthropods in greenhouses which are currently widely commercially available, yet in some cases permits for their use have been declined (Paula et al., 2021).

4.3 | Regional cooperation

Regional cooperation in biological control should be encouraged and fostered across the EPPO region and beyond. This is particularly important for research and collaboration in classical biological control techniques, but it can also facilitate the technology transfer of augmentative biological control.

Classical biological control programmes are long-term investments that demand careful planning and a precautionary approach. The involvement and cooperation of stakeholders is necessary for the implementation and monitoring of progress whereas public engagement and approval are essential.

Regional cooperation is essential for a harmonized and joined-up approach to the management of regulated pests. Take, for example, the recent occurrence of *Diaphorina citri* Kuwayama (Hemiptera: Liviidae): EPPO A1 pest) in the EPPO region (Israel 2022 and Cyprus 2023) (EPPO, 2022, 2023a). As a vector of *Candidatus Liberibacter* spp., these pests have the potential to devastate the Mediterranean citrus growing region. The BCA *Tamarixia radiata* (Waterston) (Hymenoptera: Eulophidae) has been successfully used against *D. citri* in other regions of the world and a regional approach can act to facilitate its successful use in the EPPO region. Countries at risk from *D. citri* can collectively conduct research and implementation activities while in parallel they can prepare the groundwork for a risk assessment.

4.4 | Regional guidance

It is important to develop regional guidance for a biological control framework. Priorities for EPPO Standards are developed in the Joint EPPO/IOBC Panel on Biological Control Agents and agreed and approved at the country level by the EPPO Working Party on Phytosanitary Regulation and the EPPO Council, respectively (see Section 3.2. for the current PM 6 Standards). New Standards are developed in consultation with the Joint EPPO/IOBC Panel on Biological Control Agents. Two new Standards are to be developed in 2025: (1) a Standard on host specificity testing of invertebrate BCAs for invertebrate pests and (2) a Standard on establishment potential of augmentative BCAs.

To promote harmonization, countries may utilize EPPO PM 6 Standards in national regulations.

4.5 | Pre-emptive biological control

Countries and networks should consider initiating pre-emptive biological control against priority regulated pests currently absent from the EPPO region. Pre-emptive biological control requires careful communication with all stakeholders, including the public. In the case of the pre-emptive biological control programme against *H. halys* in New Zealand, representatives from many cooperatives of various commodities (apples, pears, stone fruits, tomatoes, grapes etc.) formed the brown marmorated stinkbug (BMSB) Council (GIA, 2024), which applied for pre-emptive biological control to the New Zealand Environmental Protection Authority. However, at the same time, notifications were sent to the Ministry of Environment Primary Industries, the Department of Conservation and other crown entities and local authorities such as Māori organizations, NGOs and stakeholders who had expressed an interest in being notified about applications for new organisms (e.g. Environmental Protection Authority, 2018). The BMSB Council also runs ongoing public, importer and tourist awareness campaigns for the BMSB. In addition, an oversight committee involving industry, government and research representatives was established to rapidly approve to release a BCA for BMSB. Now *T. japonicus* is approved for conditional release in the event that a population of *H. halys* is detected (Caron et al., 2021).

4.6 | Contingency plans

When relevant, biological control techniques should be included in contingency planning to ensure biological control is integrated, where possible, into emergency measures and to understand any regulatory difficulties for their use. This can also act to raise awareness of the use of biological control among a broad spectrum of stakeholders involved with contingency planning. Under Regulation (EU) 2016/2031 Commission implementing Regulation (EU) 2023/1584, EU Member States should draw up and keep up to date for each (EU) priority pest a contingency plan. These contingency plans should be tested in simulation exercises to assess preparedness for a pest outbreak (Aragón et al., 2022; Tanner et al., 2019). During simulation exercises, further understanding could be gained on stakeholders' perception of BCAs and constraints on their use.

4.7 | Utilization of biological control in IPM

Implementing a biological control programme against a regulated pest relies on the rational use of chemical pesticides so as not to disrupt the abundance of the BCA and its life cycle. This is important when natural enemies are released in classical and augmentative biological control programmes, but also when indigenous natural enemies already present in an area are expected to make at least some impact on exotic pests (opportunistic biological control) (de Pedro et al., 2021; Torres & Bueno, 2018). Conserving and enhancing natural enemies does not require environmental risk assessment and therefore does not meet regulatory hurdles. In this case, National Plant Protection Organisations, agronomists and farmers cooperatives can play a key role in considering biological control as part of an IPM approach.

Apart from the use of chemical pesticides, other management measures and practices (cultural and production practices) that are utilized as part of an IPM strategy can interact with BCAs and therefore there is a need to ensure integration of all components to achieve the best level of management. This can be facilitated through scientific knowledge, direct communication and information exchange (Galli et al., 2024) (e.g., workshops, guidance documents).

5 | CONCLUSION

Facilitating the recommendations detailed in this paper will help mitigate the uncertainty and promote the uptake of biological practices against regulated pests in the EPPO region. The Joint EPPO/IOBC Panel on Biological Control Agents will continue to foster harmonization and progress the safe use of BCAs, and at the same time develop Standards that encourage best practice.

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APPENDIX 1 - CASE STUDIES

TORYMUS SINENSIS (HYMENOPTERA; TORYMIDAE)

One of the recent successful cases of classical biological control of alien invasive species in the EPPO region is the introduction of the parasitoid *Torymus sinensis* for biological control of *Dryocosmus kuriphilus* Yasumatsu (Hymenoptera; Cynipidae), which is an EPPO A2 pest and an EU Protected Zone Quarantine pest (Annex III). It is a pest on chestnuts (*Castanea*) that are native to China (Avtzis et al., 2019; Gibbs et al., 2011) and have been accidentally introduced with infested plant material to other parts of Asia, North America and Europe (CABI, 2016; EFSA, 2010). It is considered as one of the most serious pests of chestnuts as it seriously impacts yield (Battisti et al., 2014) and tree vigour (Sartor et al., 2015; Ugolini et al., 2014).

Torymus sinensis has successfully been used as a classical BCA against *D. kuriphilus* in Japan (Aebi et al., 2006; Gyoutoku & Uemura, 1985), the United States (Cooper & Rieske, 2007, 2011), and across Europe where *Castanea* is grown (Avtzis et al., 2019; Borowiec et al., 2014; Matošević et al., 2017; Nieves-Aldrey et al., 2019; Quacchia et al., 2008). Like *D. kuriphilus*, *Torymus sinensis* is native to China. The parasitoid is highly specific, with a biology perfectly synchronized with its host. After release, it spreads very quickly by active flight or aided by the wind, which enables the parasitoid to cover huge distances in short periods of time (Colombari & Battisti, 2016a; Matošević et al., 2017). When host populations are high, it builds its population very quickly and reaches high parasitism rates, which enables it to lower the host population quickly and efficiently (Avtzis et al., 2019; Matošević et al., 2017). Post-release studies on the effects of *T. sinensis* showed that it has no unacceptable impacts on non-target species and that it can be safely used as a BCA (Ferracini et al., 2017; Gil-Tapetado et al., 2023). *Torymus sinensis* has stable and genetically diverse populations, which is not always the case with introduced classical BCAs (Matošević et al., 2017). All these traits have enabled it to lower host populations quickly to pre-epidemic levels (Colombari & Battisti, 2016b; Matošević et al., 2017).

TAMARIXIA DRYI (HYMENOPTERA: EULOPHIDAE)

Tamarixia dryi [Waterston: Classical BCA (PM 6/3)] is a classical BCA of *Trioza erytreae* Del Guercio (Hemiptera: Triozidae), a vector of Citrus greening (‘*Candidatus Liberibacter africanus*’, ‘*Ca. Liberibacter americanus*’ and ‘*Ca. Liberibacter asiaticus*’: EPPO A1 Pests). *Trioza erytreae* [EPPO A2 pest and a regulated

EU A2 Quarantine pest (Annex II B)] transmits the bacterium under natural conditions in Africa, parts of the Arabic peninsula and some Indian Ocean islands (Gottwald, 2010; McClean & Oberholzer, 1965). *Trioza erytreae* is an EPPO A2 pest and a regulated EU A2 Quarantine pest (Annex II B).

Tamarixia dryi was utilized on the island of Réunion in the 1970s. As part of the TROPICSAFE EU funded project, research was undertaken on the potential to use *T. dryi* in Europe (Urbaneja-Bernat et al., 2019). Host range testing showed that *T. dryi* only attacks *T. erytreae*. The parasitoid was released in spring 2018 in Tenerife. It was originally released in the north of the island and 6 months later it had spread throughout the island. It was also found in other Canary Islands. In Tenerife, Gran Canaria and La Palma, the proportion of orchards with *T. erytreae* had significantly reduced, highlighting an impact of the BCA. In mainland Spain, the parasitoid was released in Galicia in 2019 and 2020, and within 6 months it had spread more than 20 km from the point of release. Eighteen months later and with more than 45 releases, it had spread widely. In Pontevedra, A Coruña and Lugo, significant decreases in the proportion of orchards infested with *T. erytreae* were recorded (Pérez-Rodríguez et al., 2019).

HETERORHABDITIS BACTERIOPHORA (RHABDITIDA: HETERORHABDITIDAE)

Popillia japonica Newman (Coleoptera: Scarabaeidae) was detected in northern Italy in 2014 and now affects a considerable area of northern Italy and southern Switzerland. It is a highly polyphagous species. Adults can be found feeding on a wide range of trees, shrubs, wild plants and crops whereas larvae feed on roots in the soil (EPPO, 2024a). *Popillia japonica* is an EPPO A2 pest and a regulated EU A2 Quarantine pest (Annex II B).

Heterorhabditis bacteriophora is a nematode species that is widely available, including for augmentative biological control of *P. japonica* larvae (grubs) in the soil. In earlier studies it was determined that indigenous northern Italian strains were efficient for controlling *P. japonica* (Marianelli et al., 2018). In fact, native *H. bacteriophora* and *Steinernema carpocapsae* were frequently found to infect *P. japonica* larvae in surveys (Glazer et al., 2022). Commercially produced strains of *H. bacteriophora* caused 46% grub mortality in field trials in northern Italy (Paoli et al., 2017). In Italy there are restrictions for releasing non-indigenous nematodes and therefore the search for local and better adapted strains is advised (Gotta et al., 2023; Torrini et al., 2020). It is important to mention that the indigenous nematodes responded in a density-dependent manner to the presence of *P. japonica* but the extent of possible cascading effects on native scarab beetle populations remains to be thoroughly assessed (Glazer et al., 2022).

TRICHOGRAMMA SPP. (HYMENOPTERA: TRICHOGRAMMATIDAE)

Spodoptera frugiperda (Lepidoptera; Noctuidae), the fall armyworm, is a pest of maize and other crops native to the Americas. Since 2016, it has been found in Africa, Asia and Oceania (Kenis et al., 2023). It has recently been detected in the EU (Cyprus, Greece and Romania), where it is a regulated quarantine pest (EPPO, 2024b). *Trichogramma* spp. (Hymenoptera: Trichogrammatidae) are egg parasitoids that are used as BCA against *S. frugiperda* in other continents (Li, de Freitas, et al., 2023a). However, *Trichogramma* species vary in their ability to parasitize *S. frugiperda* egg masses, which are composed of one to three layers of eggs and are usually covered with a variable number of scales and hairs (Li, Ma, et al., 2023b; Navik et al., 2024), therefore Kenis et al. (2024) preventively tested three common European *Trichogramma* spp. on *S. frugiperda* eggs in quarantine in Switzerland: *Trichogramma brassicae* Bezdenko, *T. dendrolimi* Matsumura and *T. cacoeciae* Marchal. They found significant differences in the ability of *Trichogramma* species to oviposit through the hairs and scales and to reach the lower egg layers. *T. dendrolimi* was shown to be the most efficient parasitoid of the three species tested They concluded that more *Trichogramma* spp. and other local natural enemies should be tested preemptively before *S. frugiperda* has invaded Europe.