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Accessing biological control genetic resources: the United States perspective

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Abstract The USA has been actively involved in classical biological control projects against invasive insect pests and weeds since 1888. Classical (importation) biological control relies upon natural enemies associated through coevolution with their target species at their geographic origin to also provide long-term, self-sustaining management where the pest/weed has become invasive. Biological control agents are a form of genetic resources and fall under the purview of the 1993 Convention on Biological Diversity (CBD) and its Nagoya Protocol (NP), which entered into force in 2014 to address equitable sharing of benefits arising from utilization of genetic resources. Safe and effective classical biological control agents have historically been shared among countries experiencing problems with invasive species. However, a feature of the Nagoya Protocol is that countries are expected to develop processes governing access to their genetic resources to ensure that the benefits are shared equitably—a concept referred to as "access and benefit sharing" (ABS). Although the USA is not party to the CBD nor the NP, US biological control programs are affected by these international agreements. Surveying, collecting, exporting and importing of natural enemies may be covered by new ABS regulatory processes. Challenges of ABS have arisen as various countries enact new regulations (or not) governing access to genetic resources, and the processes for gaining access and sharing the benefits from these resources have become increasingly complex. In the absence of an overarching national US policy, individual government agencies and institutions follow their own internal procedures. Biological control practitioners in the USA have been encouraged in recent years to observe best practices developed by the biological community for insect and weed biological control.

Keywords Classical biological control · Access and benefit sharing · Natural enemies, genetic resources

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Introduction

Since the cottony cushion scale program introduced the modern concept of biological pest control to the USA in 1888, the USA has been actively involved in classical biological control projects against invasive insect pests. A few years later, in 1902, a biological control program was begun in Hawaii to control the invasive shrub *Lantana camara* L. (Verbenaceae) by introducing host-specific phytophagous insects. Classical (importation) biological control relies upon natural enemies (predators, parasitoids and nematodes for insect pests and phytophagous arthropods and pathogens for weeds) associated through coevolution with their target species at their geographic origin to provide long-term, self-sustaining management where the pest/weed has become invasive (Hoddle et al. 2021; Mason et al. 2021; Sforza 2021). As biological control agents are a form of genetic resources, they fall under the purview of the 1993 Convention on Biological Diversity (CBD), an important aspect of which addresses the equitable sharing of benefits of genetic resources (the Nagoya Protocol (NP), entered into force in 2014) (Convention on Biodiversity 2011a; FAO 2016; Mason et al. 2021, 2023). Biological control agents are also utilized in mass-rearing and release programs in which agents may be provided by commercial entities (augmentative biological control) (van Lenteren et al. 2021), and natural populations of already-resident agents may be manipulated to conserve and increase their effectiveness (conservation biological control) (Zaviezo et al. 2021). Both of these approaches in some cases involve agents that were originally obtained as a result of classical biological control projects, but in other cases the agents involved are either native or have been long-established in North America so that access and benefit sharing (ABS) processes do not apply. In this paper we will focus on the practice of classical biological control and will not address these latter two approaches.

Safe and effective classical biological control agents have historically been freely shared by donor countries and between countries experiencing the same problems with invasive species. The predator of cottony cushion scale, *Novius cardinalis* (Mulsant) (Coleoptera: Coccinellidae), which has been widely distributed worldwide, is a case in point. Other examples include natural enemies of coffee berry borer, *Hypothenemus hampei* (Ferrari) (Coleoptera: Curculionidae), and *Pontederia crassipes* Mart. (Pontederiaceae), common water hyacinth. Authors of articles describing these projects should, and often do, indicate both the proximate and original source of the agents and acknowledge the assistance of local cooperators in providing them. However, a feature of the Nagoya Protocol is that the member countries are expected to develop processes that define and manage access to their genetic resources to ensure that the benefits are shared equitably. Although the USA neither ratified the CBD nor the Nagoya Protocol (Convention on Biodiversity 2011b), and therefore is not a party to these international agreements, US biological control programs are nevertheless affected by these international agreements. Clearly, as genetic resources covered by the NP, the process of surveying for and collecting, exporting and importing of natural enemies from native ranges of invasive pests are potentially covered by regulatory processes that create an ABS regime. The complexity of ABS has arisen as the various member countries have enacted (or fail to enact) new regulations, rules, and laws to implement an ABS regime, with each participant country developing its own process. As a result, the processes for gaining access and sharing the benefits from these resources have become increasingly complex.

Welch et al. (2017) reported on a survey indicating that ABS regulations may be inhibiting the exchange of genetic resources since the NP, the Food and Agriculture Organization (FAO) International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA), and other such treaties entered into force. Two explanations were proposed: (1) that the increased complexity of the regulatory environment has created new barriers, and (2) difficulty in understanding and navigating regulations ultimately results in reduced access to material. A more recent survey specifically of biological control workers was conducted by the International Organization of Biological Control (IOBC) and indicated that while some countries have facilitated access to biological control genetic resources, new requirements instituted in other countries were felt to have impeded biological control implementation to some degree (Mason et al. 2023). There was a consensus among survey respondents that support for research communities in countries providing the agents was the preferred form for benefit sharing, and that the continued free use and exchange of biological control resources benefits the wider global community.

Stance of the United States government with respect to the Nagoya Protocol

The USA is not a party to either the CBD or the Nagoya Protocol, and it has not established an overarching ABS framework governing the procedures for exchange of biological materials, including natural enemies of pests and weeds as biological control agents. However, there is general support for the ABS concept from US agencies. The US views of ABS were presented in a public webinar (Reilley 2020): (1) Measures should be clear, transparent and not arbitrary, (2) they should be consistent with commercial practice, (3) the US supports mutual agreements between providers and recipients, (4) information and materials are not equivalent, and (5) access is just as important as benefit sharing. The USA does not typically restrict access to genetic resources as a blanket policy, although at their discretion, local agencies or management units such as local, state and federal parks, and private conservation lands or landowners may have developed policies for genetic resources obtained from their sites that include some restrictions (McCluskey et al. 2017), such as those that deal with endangered species. As an example, research scientists must obtain a permit to collect in US national parks (United States National Park Service 2013).

Despite not being a member, the USA participates in CBD and NP meetings as an observer and interested party. ABS is also addressed under other bodies where the USA is a member, and as such has submitted its comments on ABS issues. None of these statements to date have specifically mentioned or discussed biological control agents, but the text of documents that have been submitted on animal and aquatic genetic resources and forest genetic resources are illustrative of US attitudes and general concerns. Two examples are statements submitted to the FAO Commission on Genetic Resources for Food and Agriculture (FAO 2019, 2021) in which the USA indicated support for numerous points relating to forest genetic resources that should be considered when dealing with access and benefit sharing. Some of these points clearly are also relevant when considering natural enemies of invasive insect pests and weeds, paraphrased here as: (1) the resources are frequently undomesticated species and populations, (2) they disperse on their own without regard to national borders, (3) their benefits can be considered "ecosystem services" for which establishing a defined value is exceedingly difficult, (4) benefits may take many years and considerable research to be documented, (5) established markets may not exist, as they do for agricultural crops, (6) the proposed solution is often found in the same region as the problem, (7) while commercial markets are less relevant in many cases, continued exchange and distribution is important for academic and public research and use, and (8) if resources are not used, they risk eventually being irretrievably lost, so their exchange should be encouraged. The issue of critical, irreversible loss of insect biodiversity resources has been addressed most recently by Donkersley et al. (2022), including the loss of predators and parasitoids as an important component of ecosystem services. Not only their exchange between interested parties, but also the preservation of their native habitats to preserve this diversity, should be encouraged. The USA also generally encourages exchange of genetic resources as a means of preserving genetic diversity in order to enhance food security (FAO 2019). Recently, ABS discussions have expanded to include consideration of digital genetic data resources, such as genetic sequencing, which are increasingly utilized in biological control programs to ensure proper characterization, identification and monitoring of agents. Concerns in this regard were cogently conveyed in a statement by the Entomological Society of America (2020).

The US comments to FAO (2021) pointed out that, as a benefit sharing best practice, the USDA encourages and provides varied types of capacity building activities for its international cooperators. These activities range from shared germplasm collections, technology transfer, co-authored publication of research, and training of scientists visiting the USA and during international visits. The USA has joined with certain specific international instruments that relate to ABS. The FAO International Treaty on Plant Genetic Resources for Food and Agriculture is one such example (FAO 2022). Furthermore, despite the lack of overarching federal ABS laws, individual US institutions are able to formulate and adopt policies that observe ABS principles. Historically, biological control researchers in US government agencies and universities have actively participated in these kinds of benefit-sharing activities with their international partners.

In their review of the impact of the NP on US taxonomic and biodiversity collections that was conducted for the US Culture Collection Network (USCCN), McCluskey et al. (2017) pointed out that the collections include large amounts of material that originated within the boundaries of other countries and were collected and deposited before the CBD or the Nagoya Protocol. Historically, many of these biodiversity collections frequently relied upon simple accession and transfer requirements, although official government agency collections utilized more formal agreements for transfer of materials. The same situation has applied to the collection and importation of classical biological control agents throughout much of the past century since the advent of classical biological control practice.

Nevertheless, there are processes pertaining to various types of exchanges. Participants at the 2017 USCCN meeting were informed that US researchers should comply with all laws, including ABS regulations enacted by the country from which they are collecting materials. Failure to do so could result in loss of access to genetic resources, grant termination, or unwelcome measures including fines or other legal actions (McCluskey et al. 2017).

Biological control researchers and practitioners in the USA have been encouraged in recent years to observe best practices developed by the biological community, such as the International Code of Best Practices for Classical Biological Control of Weeds (Balciunas and Coombs 2004) and best practices for the use and exchange of invertebrate biological control genetic resources relevant for food and agriculture (Mason et al. 2018). Absent an overarching national policy, some individual government agencies and institutions have developed their own internal procedures. Most if not all US classical biological control programs include involvement at some stage by US Department of Agriculture agencies, especially the Animal and Plant Health Inspection Service (APHIS), Agricultural Research Service (ARS), Forest Service (FS), Bureau of Land Management (BLM) and Fish and Wildlife Service (FWS).

For example, several ARS Strategic Plan Program Management Goals (United States Department of Agriculture 2022a) concern classical biological control activities: (1) to catalyze and manage domestic and international partnerships that enhance the Agency's national programs to address critical needs of US agriculture, (2) to manage ARS' overseas biological control laboratories that identify and collect natural enemies of invasive species in the USA, and (3) to network with other US government agencies and the international community to promote the Agency's interests (in sustainable pest management). ARS operates four Overseas Biological Control Laboratories (OBCLs), either directly or through cooperative agreements with host country institutions, located in France, Argentina, Australia, and China, for research on biological control of invasive weeds and insect pests of concern in the USA (United States Department of Agriculture 2022b). These laboratories support a wide range of US projects and have increased the opportunities for foreign exploration and collaboration, simultaneously providing reciprocal benefits and training to the countries hosting the laboratories and other donor countries.

ARS biological control scientists are expected to adhere to agency policies for material transfer agreements (MTAs) under Policy and Procedure 141.2-ARS/Technology Transfer (as authorized by US Executive Order 12,591 (Facilitating access to science and technology 1987) and 15 USC 3710 (Utilization of Federal Technology 2022). An MTA is used when providing ARS materials to external researchers and for receiving material from outside parties for research purposes. When projects involve collaboration beyond simple exchange of materials, formal specialized agreements are required. ARS scientists are also expected to obtain local permits that may be required, observe policies and follow procedures of the source countries when engaged in foreign exploration, collection and export of agents to the USA.

Once a potential agent has been evaluated and deemed suitable for possible field release, a petition is submitted to regulatory authorities. Organisms utilized for biological control are found within a broad taxonomic range and include herbivores, parasitoids, predators and pathogens (Sforza 2021). For arthropod natural enemies (predators and parasitoids) of insect target pests, petitions are sent to an independent panel of reviewers. Based upon the responses received, a recommendation is submitted to USDA-APHIS. The process for herbivorous biocontrol agents of weeds has additional layers of consultation, advised by a Technical Advisory Group (Cofrancesco and Shearer 2004; van Driesche and Winston 2022). Pathogens are often treated as microbial insecticides which follow a different regulatory pathway, and we have not included them in our discussion here. In recent decades, regulatory review in the USA has become more and more stringent, requiring extensive justification and evaluation data. The primary reason for regulatory oversight is to ensure that non-target impacts of agents would not occur or would not be significant. Such undesired outcomes could include impacts to threatened or endangered species and plants of economic or cultural importance, or that result from the introduced natural enemies themselves becoming a nuisance. Regulatory review does not currently address whether researchers followed the correct processes with respect to access and benefit sharing.

Implications of ABS procedures and regulations for US biological control programs

Since the advent of classical biological control over one hundred years ago with the cottony cushion scale and Lantana programs, the USA has been one of the most active countries involved in conducting classical biological control projects (Cock et al. 2016; Winston et al. 2022). However, the number of biological control programs mounted against insect pests and the number of new arthropod biological control agents introduced against weeds in the USA have both seen continual and significant declines in recent decades (van Driesche and Winston 2022). New projects for insect targets have declined by over 80% since 1985, from an average of over six per year during 1985–1989, to less than one per year during 2015–2018. Numbers of introductions of weed agents have experienced two peaks, the first during 1960–1964 and a larger peak during 1990–1994. Since the latter peak, numbers have declined following a trend comparable to that of arthropod agents. However, these declines were occurring well before the NP entered the picture. The regulation of introduced biological control agents in the USA has increased steadily over time. As pointed out by van Driesche et al. (2020), classical biological control introductions are more stringently regulated than are species introduced for any commercial purposes, which has increased the cost of research required to implement programs.

Biological control scientists and practitioners in the USA were surveyed in 2019 to assess the current state of biological control (Leppla et al. 2022). This survey identified 340 research and extension personnel who are involved either full-time or part-time in biological control programs. Of these, 218 were employed by universities, 86 by federal agencies, and 36 by state agriculture departments. Classical biological control programs primarily involved state and federal agencies, while university personnel tended to be more involved in conservation approaches.

During the years 2000 through 2014, before the Nagoya Protocol entered into force, 32 arthropod agents (and one nematode) from Argentina, Australia, China, Colombia, Dominica, Germany, Honduras, Japan, Kenya, New Zealand, Pakistan, Russia, Santo Domingo, South Africa, Taiwan, Tanzania, Thailand and Vietnam were subjects of release petitions submitted to APHIS for projects on invasive insect pests. In the six years following the 2014 implementation of the NP, six arthropod agents from France, Kenya (via Colombia), South Korea, Russia and Spain have been subjects of submitted release petitions (Table 1). From 2000 through 2014, 28 herbivorous agents of invasive weeds were obtained from 18 countries in South America, Europe, Asia and Australia and released in the USA. In the six subsequent years following 2014, 11 herbivorous agents of weeds from at least 11 countries have been released against invasive weed targets (Table 2). Of course, some of the agents released or petitioned for release during the several years immediately following 2014 were already received in the USA and in the research pipeline before the Nagoya Protocol was officially in force and likely were not subject to any new procedures instituted by countries of origin. It is also worth mentioning that there are agents currently being evaluated in quarantine facilities as potential biological control agents of invasive insects such as *Halyomorpha halys* (Stål) (Hemiptera: Pentatomidae) (brown marmorated stinkbug), *Lycorma delicatula* (White) (Hemiptera: Fulgoridae) (spotted lanternfly), *Bagrada hilaris* (Burmeister) (Hemiptera: Pentatomidae) (bagrada bug) and *Cactoblastis cactorum* (Berg) (Lepidoptera: Pyralidae) (cactus moth) and weeds such as *Vincetoxicum* spp.

Table 1 Petitions submitted to USDA APHIS from 2000 to 2020 requesting permits for release of biological control agents of target insect pests in the USA

Year	Target	Agent	Geographic origin
2002	*Lilioceris lilii* Scopoli—lily leaf beetle	*Olesicampe errabundus* (Grav.) (Hymenoptera: Ichneumonidae)	Germany
2002	*Lilioceris lilii* Scopoli—lily leaf beetle	*Diaparsis jucunda* (Holmgren) (Hymenoptera: Ichneumonidae)	Germany
2004	*Ceratitis capitata* Wiedemann—Mediterranean fruit fly	*Fopius ceratitivorus* Wharton (Hymenoptera: Braconidae)	Kenya
2005	*Homalodisca coagulata* Say—Glassy-winged sharpshooter	*Gonatocerus tuberculifemur* (Hymenoptera: Mymaridae)	Argentina
2005	*Lymantria dispar* (L.)—Gypsy moth (= spongy moth)	*Nosema portugal* Maddox & Vavra *Nosema lymantriae* Weiser *Vairimorpha disparis* (Timofejva) (all Microsporidia)	Portugal Bulgaria
2005	*Diaprepes abbreviatus* (L.)—Diaprepes root weevil	*Haeckeliania* n. sp. & *Haeckeliania sperata* Pinto (Hymenoptera: Trichogrammatidae)	Columbia
2005	*Diaprepes abbreviatus* (L.)—Diaprepes root weevil	*Fidobia dominica* Evans and Peña (Hymenoptera: Platygasteridae)	Dominica
2005	*Phyllocnistis citrella* Stainton—Citrus leafminer	*Citrostichus phyllocnistoides* (Naryanin) (Hymenoptera: Eulophidae)	Taiwan
2005	*Bactrocera oleae* (Rossi)—Olive fly	*Psyttalia lounsburyi* Sylvestri (Hymenoptera: Braconidae)	South Africa
2005	*Solenopsis invicta* Buren & S. *richeteri* Forel—imported fire ant	*Pseudacteon obtusus* Bergmeier (Diptera: Phoridae)	Argentina
2006	*Sirex noctilio* Fab.—Sirex woodwasp	*Deladenus* (= *Beddingia*) *siricidicola* (Bedding) (Tylenchida: Neotylenchidae)	New Zealand (adventive from Japan or Europe)
2006	*Bactrocera oleae* (Rossi)—olive fly	*Psyttalia ponerophaga* (Sylvestri) (Hymenoptera: Braconidae)	Pakistan
2006	*Eucalyptolyma maideni*—spotted gum psyllid	*Psyllaephagus* sp. nr. *hirtus* (Hymenoptera: Encyrtidae)	Australia
2006	*Aphis glycines* Matsumura—soybean aphid	*Binodoxys communis* (Gahan) (Hymenoptera: Braconidae)	China, Inner Mongolia
2006	*Eucalyptolyma maideni*—spotted gum psyllid	*Psyllaephagus parvus* Riek (Hymenoptera: Encyrtidae)	Australia
2007	*Agrilus planipennis* (Fairmaire)—Emerald ash borer	*Spathius agrili* Yang (Hymenoptera: Braconidae)	China
2007	*Metamasius callizona* (Chevrolat)—bromeliad beetle	*Lixadmontia franki* Wood (Diptera: Tachinidae)	Honduras
2007	*Quadrastichus erythrinae* Kim—Erthina gall wasp	*Eurytoma erythrinae* Gates & Delvare (Hymenoptera: Eurytomidae)	Tanzania
2008	*Darna pallivitta* (Moore)—nettle caterpillar	*Aroplectrus dimerus* Lin (Hymenoptera: Eulophidae)	Taiwan
2008	*Diaphorina citri* Kuwayama—Asian citrus psyllid	*Tamarixia radiata* (Waterson) (Hymenoptera: Eulophidae)	Vietnam
2008	*Hypothenemus hampei* (Ferrari)—coffee berry borer	*Cephalonomia stephanoderis* Betrum (Hymenoptera: Bethylidae)	Santo Domingo
2008	*Hypothenemus hampei* (Ferrari)—coffee berry borer	*Phymasthicus coffea* (LaSalle) [Eulophidae] & Prorops nasuta (LaSalle) (Hymenoptera: Bethylidae)	Columbia (originally from Kenya)
2009	*Adelges tsugae* Annand—hemlock wooly adelgid	*Laricobius osakensis* Montgomery& Shiyake (Coleoptera: Derodontidae)	Japan

Table 1 (continued)

Year	Target	Agent	Geographic origin
2009	*Planococcus citri* (Risso)—citrus mealybug *P. ficus* (Signoret)—vine mealybug	*Coccidoxenoides perminutus* Girault (Hymenoptera: Encyrtidae)	South Africa
2010	*Solenopsis invicta* Buren—red imported fire ant *S. richteri* Forel—black imported fire ant	*Pseudacteon cultellatus* Borgmeier (Diptera: Phoridae)	Argentina
2010	*Aulacaspis yasumatsui* Takagi – Cycad aulacaspis scale	*Phaenochilus* n.sp. & *Phaenochilus kashaya* Giorgi & Vandenberg (Coleoptera: Coccinellidae)	Thailand
2011	*Aphis glycines* Matsumura—soybean aphid	*Binodoyxs koreanus* Stary (Hymenoptera: Braconidae)	South Korea
2011	*Aphis glycines* Matsumura—soybean aphid	*Aphelinus rhamni* Woolley & Hopper (Hymenoptera: Aphelinidae)	China
2013	*Agrilus planipennis* Fairmaire—Emerald ash borer	*Spathius galinae* Belolkbylskij & Strazanae (Hymenoptera: Braconidae)	Russia
2014	*Aulacapsis yasumatsui* Takagi—cycad aulacaspis scale	*Phaenochilus kashaya* Giorgi & Vandenberg (Coleoptera: Coccinellidae)	Thailand
2014	*Adelges tsugae* Annand—Hemlock woolly adelgid	*Scymnus camptodromus* Yu and Liu (Coleoptera: Coccinellidae)	China
2016	*Agrilus planipennis* Fairmaire—emerald ash borer	*Oobius primorskyensis* Yao & Duan (Hymenoptera: Braconidae)	Russia
2016	*Drosophila suzukii* Matsumura—spotted wing Drosophila	*Leptopilina japonica* Novković & Kimura (Hymenoptera: Figitidae)	South Korea
2017	*Diuraphis noxia* (Kurdjumov)—Russian wheat aphid	*Aphelinus hordei* Kurdjumov (Hymenoptera: Aphelinidae)	France
2019	*Drosophila suzukii* Matsumura—spotted wing Drosophila	*Ganaspis brasiliensis* (Ihering) (Hymenoptera: Figitidae)	South Korea
2019	*Euphyllura olivina* (Costa)—olive psyllid	*Psyllaephagus euphyllurae* (Masi) (Hymenoptera: Encyrtidae)	Spain
2020	*Hypothenemus hampei* (Ferrari)—coffee berry borer	*Phymastichus coffea* LaSalle (Hymenoptera: Eulophidae)	Columbia, originally from Kenya

Petitions are listed by year of submission

(Apocynaceae) (swallow-worts) and *Genista monspessulana* (L.) L.A.S. Johnson (Fabaceae) (French broom), for which release petitions have not yet been submitted, from various source countries including Argentina, China, France and Pakistan. The 2019 practitioner survey asked respondents to prioritize among 14 topics perceived as being of greatest importance for the continued practice of biological control. Classical biological control was the third-highest of these (Leppla et al. 2022). Funding for biological control and the incorporation of biological control into integrated pest management respectively received the second and top rankings. Since 2014, exploratory surveys by USDA and cooperators for other agents conducted in native range countries have resulted in agents obtained for further research in the USA from Asia (China, South Korea, Pakistan, Thailand, Vietnam), Australia, Europe (Albania, Bulgaria, Cyprus, France, Greece, Italy, Spain), Republic of South Africa and South America (Argentina, Brazil, Paraguay, Uruguay), demonstrating that biological control projects are still proceeding in the USA, though at a rate that is greatly diminished from earlier decades.

Conclusions

Clearly, the increasing administrative complexity and cost of conducting the research necessary for petitions are important contributing causes of the decline in the number of classical biological control research

Table 2 Field releases of herbivorous arthropod weed agents for classical biological control from 2000 to 2022 in the USA (regardless of outcome)

Year	Target	Agent	Geographic origin
2000	*Spartina alterniflora* Loisel.—saltmarsh cordgrass	*Prokelisia marginata* (Van Duzee) (Hemiptera: Delphacidae)	Regional in USA (intoduced to other regions in USA and Europe)
2001	*Cirsium vulgare* (Savi) Ten.—spear thistle	*Cheilosia grossa* (Fallén) (Diptera: Syrphidae)	Europe (widespread)
2001	*Euphorbia esula* L.—leafy spurge	*Spurgia capitigena* (Bremi) (Diptera: Cecidomyiidae)	Italy
2001	*Salvinia molesta* D.S. Mitch.—giant salvinia	*Cyrtobagous salviniae* Calder & Sands (Coleoptera: Curculionidae)	Brazil
2001	*Tamarix* spp.—salt cedar	*Diorhabda carinulata* (Desbrochers) (Coleoptera: Chrysomelidae)	China, Kazakhstan
2002	*Salvinia minima* Baker—common salvinia	*Cyrtobagous salviniae* Calder & Sands (Coleoptera: Curculionidae)	Brazil
2002	*Chondrilla juncea* L.—rush skeletonweed	*Bradyrrhoa gilveolella* (Treitschke) (Lepidoptera: Pyralidae)	Greece
2002	*Jacobaea vulgaris* Gaertn.—common ragwort	*Longitarsus jacobaeae* (Waterhouse) (Coleoptera: Chrysomelidae)	Italy and Switzerland
2002	*Melaleuca quinquenervia* (Cav.) S.T.Blake—broad-leaved paperbark	*Boreioglycaspis melaleucae* Moore (Hemiptera: Psyllidae)	Australia
2003	*Solanum viarum* Dunal—tropical soda apple	*Gratiana boliviana* Spaeth (Coleoptera: Chrysomelidae)	Paraguay
2003	*Spartina anglica* C.E.Hubb.—common cordgrass	*Prokelisia marginata* (Van Duzee) (Hemiptera: Delphacidae)	regional in USA (introduced to other regions in USA and Europe)
2003	*Tamarix* spp.—salt cedar	*Diorhabda carinulata* (Desbrochers) (Coleoptera: Chrysomelidae)	China
2003	*Tamarix* spp.—salt cedar	*Diorhabda elongata* (Brullé) (Coleoptera: Chrysomelidae)	Greece (Crete)
2004	*Centaurea jacea* L.—brown knapweed	*Larinus obtusus* Gyllenhal (Coleoptera: Curculionidae)	Romania & Serbia
2004	*Centaurea nigra* L.—common knapweed	*Larinus obtusus* Gyllenhal (Coleoptera: Curculionidae)	Romania & Serbia
2004	*Lygodium microphyllum* (Cav.) R.Br.—old world climbing fern	*Austromusotima camptozonale* (Hampson) (Lepidoptera: Crambidae)	Australia
2004	*Persicaria perfoliata* (L.) H. Gross—mile-a-minute weed	*Rhinoncomimus latipes* Korotyaev (Coleoptera: Curculionidae)	China
2004	*Tamarix* spp.—salt cedar	*Diorhabda sublineata* (Lucas) (Coleoptera: Chrysomelidae)	Tunisia
2005	*Melaleuca quinquenervia* (Cav.) S.T.Blake—broad-leaved paperbark	*Fergusonina turneri* Taylor (Diptera: Fergusoninidae)	Australia
2005	*Tamarix* spp.—salt cedar	*Diorhabda elongata* (Brullé) (Coleoptera: Chrysomelidae)	Greece
2006	*Tamarix* spp.—salt cedar	*Diorhabda carinata* (Faldermann) (Coleoptera: Chrysomelidae)	Uzbekistan
2008	*Lygodium microphyllum* (Cav.) R.Br.—old world climbing fern	*Floracarus perrepae* Knihinicki & Boczek (Acari: Eriophyidae)	Australia
2008	*Lygodium microphyllum* (Cav.) R.Br.—old world climbing fern	*Neomusotima conspurcatalis* (Warren) (Lepidoptera: Crambidae)	Australia
2008	*Melaleuca quinquenervia* (Cav.) S.T.Blake—broad-leaved paperbark	*Lophodiplosis trifida* Gagné (Diptera: Cecidomyiidae)	Australia
2008	*Linaria vulgaris* Mill.—yellow toadflax	*Rhinusa linariae* (Panzer) (Coleoptera: Curculionidae)	Europe (central, southern), Russia (southern) via Canada (BC)

Table 2 (continued)

Year	Target	Agent	Geographic origin
2009	*Arundo donax* L.—giant reed	*Tetramesa romana* (Walker) (Hymenoptera: Eurytomidae)	France, Spain
2009	*Rhaponticum repens* (L.) Hidalgo—Russian knapweed	*Aulacidea acroptilonica* Tyurebaev (Hymenoptera: Cynipidae)	Uzbekistan
2009	*Rhaponticum repens* (L.) Hidalgo—Russian knapweed	*Jaapiella ivannikovi* Fedotova (Diptera: Cecidomyiidae)	Uzbekistan
2010	*Arundo donax* L.—giant reed	*Rhizaspidiotus donacis* (Leonardi) (Hemiptera: Diaspididae)	France, Spain
2010	*Pontederia crassipes* Mart.—common water hyacinth	*Megamelus scutellaris* Berg (Hemiptera: Delphacidae)	Argentina
2011	*Psidium cattleianum* Afzel. ex Sabine—strawberry guava	*Tectococcus ovatus* Hempel (Hemiptera: Eriococcidae)	Brazil
2011	*Dioscorea bulbifera* L.—air potato	*Lilioceris cheni* Gressitt & Kimoto (Coleoptera: Chrysomelidae)	China, Nepal
2011	*Pilosella aurantiaca* (L.) F.W.Schultz & Sch. Bip.—orange hawkweed	*Aulacidea subterminalis* Niblett (Hymenoptera: Cynipidae)	Switzerland
2013	*Senecio madagascariensis* Poir.—Madagascar fireweed	*Secusio extensa* (Butler) (Lepidoptera: Erebidae)	Madagascar
2013	*Delairea odorata* Lem.—Cape ivy	*Secusio extensa* (Butler) (Lepidoptera: Erebidae)	Madagascar
2013	*Pontederia crassipes* Mart.—common water hyacinth	*Megamelus scutellaris* Berg (Hemiptera: Delphacidae)	Argentina, Paraguay
2016	*Dioscorea bulbifera* L.—air potato	*Lilioceris cheni* Gressitt & Kimoto (Coleoptera: Chrysomelidae)	China, Nepal
2016	*Delairea odorata* Lem.—Cape ivy	*Parafreutreta regalis* Munro (Diptera: Tephritidae)	South Africa
2017	*Arundo donax* L.—giant reed	*Lasioptera donacis* Coutin (Diptera: Cecidomyiidae)	South Europe (Mediterranean)
2017	*Vincetoxicum rossicum* (Kleopow) Barbar.—European swallowwort	*Hypena opulenta* (Christoph) (Lepidoptera: Erebidae)	Ukraine
2019	*Lepidium draba* L.—hoary cress	*Aceria drabae* (Nalepa) (Acari: Eriophyidae)	Greece, Bulgaria
2019	*Schinus terebinthifolia* Raddi—Brazilian peppertree	*Pseudophilothrips ichini* (Hood) (Thysanoptera: Phlaeothripidae)	Brazil
2019	*Linaria vulgaris* Mill.—yellow toadflax	*Rhinusa pilosa* (Gyllenhal) (Coleoptera: Curculionidae)	Serbia
2020	*Centaurea solstitialis* L.—yellow star-thistle	*Ceratapion basicorne* (Illiger) (Coleoptera: Brentidae)	Greece
2020	*Ulex europaeus* L.—gorse	*Sericothrips staphylinus* Haliday (Thysanoptera: Thripidae)	Hawaii (introduced range)
2020	*Fallopia sachalinensis* (F.Schmidt) Ronse Decraene—giant knotweed	*Aphalara itadori* Shinji (Hemiptera: Psyllidae)	Japan
2020	*Fallopia japonica* (Houtt.) Ronse Decraene—Japanese knotweed	*Aphalara itadori* Shinji (Hemiptera: Psyllidae)	Japan
2020	*Fallopia* × *bohemica* (Chrtek & Chrtková) J.P. Bailey—Bohemian knotweed	*Aphalara itadori* Shinji (Hemiptera: Psyllidae)	Japan
2022	*Melaleuca quinquenervia* (Cav.) S.T. Blake -broad-leaved paperbark	*Lophodiplosis indentata* Gagné (Diptera: Cecidomyiidae)	Australia

[a]Source country information for agents not listed in Winston et al. (2022) was obtained from various forms of project documentation located in internet searches

Releases are listed by year in which they first occurred. Based on[a] Winston et al. (2022)

programs, as are concerns about continued access to potential new agents, indicated by van Lenteren (2021) and in the survey by Mason et al. (2023). New ABS policies and uncertainty in dealing with such policies are partly responsible for this administrative complexity, as are uncontrollable events like the Covid-19 pandemic that impact travel, although they are not the sole cause. As more countries develop their ABS processes in accordance with the Nagoya Protocol, further changes can be anticipated that may be either positive or negative, and it will continue to be important for the biological control community to remain engaged in the discussion. Nevertheless, classical biological control can be expected to remain a valuable approach for long-term insect pest suppression with corresponding economic benefits (Naranjo et al. 2015).

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Declarations

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