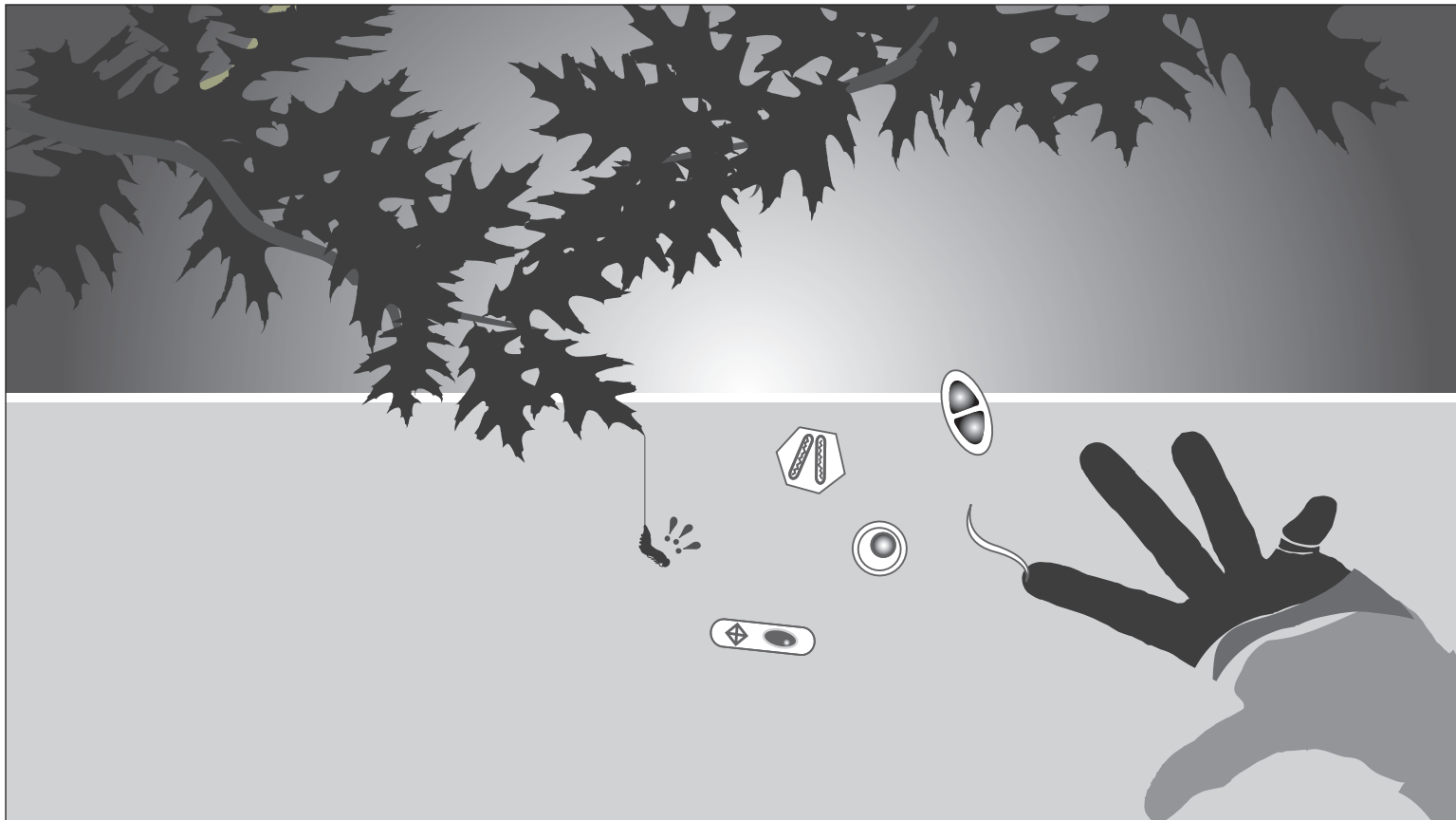




United States Department of Agriculture

Classical Biological Control of Insects and Mites: A Worldwide Catalogue of Pathogen and Nematode Introductions



Forest
Service

Forest Health Technology
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The Forest Health Technology Enterprise Team (FHTET) was created in 1995 by the Deputy Chief for State and Private Forestry, Forest Service, U.S. Department of Agriculture, to develop and deliver technologies to protect and improve the health of American forests. This book was published by FHTET as part of the technology transfer series.

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Cover Image

Dr. Vincent D'Amico, Research Entomologist, U.S. Forest Service, Urban Forestry Unit, NRS-08, Newark, Delaware.

Cover image represents a gypsy moth (*Lymantria dispar*) larva silking down from the leaves of an oak (*Quercus*) tree and being exposed to a diversity of pathogens (a fungus, a bacterium, a virus and a microsporidium) and a nematode that are being released by a human hand for biological control (*not drawn to scale*).

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INTRODUCTION

Classical biological control is a strategy that has been defined as “The intentional introduction of an exotic biological control agent for permanent establishment and long-term pest control” (Eilenberg et al. 2001).

Numerous summaries of the many classical biological control programs have been published (e.g., Cock et al. 2016, Hajek et al. 2007, Winston et al. 2014). This strategy has been used extensively to control weeds and arthropods pests. For control of weeds phytophagous arthropods have principally been used and for control of arthropod pests parasitoids and predators have principally been used (Hajek 2004).

Most programs using pathogens and nematodes for control of insects and mites have focused on mass production and inundative release. As long-term solutions for insect and mite pests (i.e., use in classical biological control programs), pathogens and nematodes have been used much less frequently when compared with parasitoids and predators (Hajek et al. 2007). Interestingly, while some classical biological control programs using pathogens and nematodes have been very successful in controlling insect and mite pests, some accidental introductions of entomopathogenic agents have also yielded substantial and long-term control.

This publication is an updated version of the catalogue of classical biological control of pathogens and nematodes published in 2005 (Hajek et al. 2005). For both this revision and the initial version, it has been difficult to find many of the classical biological control programs listed in the tables that follow; possibly, we have not listed them all. Likewise, it was often difficult determining whether a release program should be included in this catalogue, particularly when a program was implemented many years ago and/ or not thoroughly documented. Thus, we used the following criteria for including programs in this catalogue:

1. The target pest was an insect or mite.
2. The microbial pathogen or nematode was not native (an exotic) to the area of release. We have included programs where the species of microbe or nematode was exotic (introduced) as well as programs where only the strain or biotype released was exotic.

We included programs for which, whether the releases were successful or not, the establishment of the microbe appeared to be a goal (i.e., long-term establishment and control) and establishment was either investigated or discussed or, for older programs, we can infer that establishment of the pathogen or nematode was a goal of the program. Note: Intentionally, we did not include examples of early widespread introductions of entomopathogens that were later shown to be questionably pathogenic, or widespread introductions where contaminants were actually released instead of the intended organisms (e.g., see Carruthers et al. 1996, Hostetter and Dysart 1996, Tanada and Kaya 1993).

Organization of the Tables

Intentional releases of entomopathogens against target insect or mite pests are grouped according to specific pathogen and nematode groups, and presented in Tables A through F. Table G summarizes accidental introductions. The following categories of information are covered for each introduction:

Pest Group and Species

Within each table the information is organized by the order and family of pest species (hosts) as laid out in the Table of Contents and Appendix II; within a family, the species entries are alphabetical. Only pestiferous insect and mite hosts are included. Taxonomic grouping, scientific names and synonyms for species names used in the publications cited or in the literature, are provided. If known, common names for pests are included.

Biological Control Agent

All natural enemies listed are exotic to their respective areas of release, i.e., either the species or the strain released was exotic, and include viruses, bacteria, fungi (including microsporidia in a separate table), an oomycete, and nematodes. For the majority of these groups, the higher order classification is presently not known or is being revised and Appendix I was constructed accordingly. Scientific names and synonyms are provided, and the family of the pathogen or nematode (or clade, for microsporidia). Higher levels of taxonomic classification are provided in Appendix I.

Release Country or Region

Releases are presented separately for geographically isolated areas and are listed by the country where the release was made. In some cases, a pathogen or nematode was released in more than one area within the same country. If release areas are geographically isolated from one another, these introductions are considered separate introductions. The exception to this would be the release of a pathogen or nematode on proximate islands of the same country, e.g., in the many island groups in the south Pacific. If it appears that the introductions of pathogens or nematodes on proximate islands within a group were part of the same program, only the initial introduction is listed.

Year of Release

The year of release is listed, providing the intent of the release was to establish the pathogen or nematode in the release area. In some cases, after release the pathogen or nematode levels declined over time, so agents were re-introduced. In other cases, pathogens have been re-introduced throughout a region over a period of years because the agents spread slowly on their own. In both cases, we list only the year or years of the initial releases; the dates of second or third introductions, or releases in later years in the same general region, are included only if the initial release failed or establishment was highly questionable, or the pathogens used in subsequent releases were from a different source or sources. For multiple releases of a biological control agent against the same target pest, table entries are ordered chronologically by year of first release. In the case of accidental introductions (Table G), the year the agent was first found is listed.

Source of the Biological Control Agent

The geographical location where the pathogen or nematode was acquired for the release is provided, if known (e.g., *ex China*). Whenever appropriate, microbes from different source locations are listed separately. In some cases, the origin of the natural enemies that were released is not known and the area where the natural enemy is native is given with an explanation. This can happen when natural enemies are introduced to one location (X) and then collected from location X for release in another location (Y), instead of directly acquiring them from the area where they are native.

Results from Introduction

Results of introductions are provided as brief summaries of establishment, control, and persistence. We found that it is not always easy to classify control programs by strategy (i.e., classical biological control vs. inundative augmentation) and there are multitudes of programs where pathogens and nematodes have been released inundatively. For studies to be included in Tables A-F, there must be some documented evidence that, whether the pathogen persisted or not after release, the intent of the program was to establish the pathogen in the release area for long-term, not temporary, control. Some older, poorly documented programs are exceptions and are included when we inferred the goal was establishment. Clear summaries of results from introductions cannot always be found. In some cases, this is because not enough time has transpired since the release to see an effect. Unfortunately, in other cases, especially in earlier programs, we simply could find no documentation of what happened after releases.

Pest Origin

For each pest species, its status in the country of release of the biological control agent is listed as either Introduced (exotic); Native (endemic); or Unknown. In some cases of widespread distribution within a region or continent, the species is assumed to be native if no other information was readily available.

References (within Tables)

Citation numbers for each table entry are provided, corresponding to the numerical list of references given before the index.

Appendices

Following Tables A-G, Appendix I provides the classification for pathogens and nematodes included in the catalogue. Appendix II provides the classification for insect and mite hosts, targeted by pathogens or nematodes that were either intentionally or accidentally introduced.

References

The full list of numbered references that follows the Appendices does not include every mention of a classical biological control introduction of a pathogen or nematode. Rather, it includes selected sources providing the information presented in this catalogue. If the information included in the catalogue has not been published, the individual providing the information is cited.

TABLE A: Exotic Viruses Released, by Target Pest

PEST ORDER: FAMILY Target pest species	Biological control agent; (Family: <i>Genus</i>)	Release country or region	Year of release	(<i>Source of biological control agent</i>) Results from introduction	Pest origin	References
COLEOPTERA: SCARABAEIDAE						
<i>Oryctes monoceros</i> (Olivier); African rhinoceros beetle or Coconut beetle	<i>Oryctes rhinoceros nudivirus (OrNV)</i> [= <i>Rhabdionvirus oryctes</i> (Huger); = <i>Baculovirus oryctes</i> Huger]; (Nudiviridae: <i>Alphanudivirus</i>)	SEYCHELLES (in the Indian Ocean)	1973	(<i>ex Samoa</i>) Released on Mahé, Praslin Island group and La Digue. Establishment confirmed in 1986 on Praslin Island group only, with infection 70-90%.	Native	112, 113
			1981-83	(<i>ex Praslin Island group, Seychelles</i>) Established on Mahé and Ste. Anne with 20-50% infection and 30% reduction in beetle population.	Native	112, 113
		TANZANIA	1983-87	(<i>ex Philippines and Samoa</i>) Established at 2 sites, with 40-60% infection after 1-1.5 years but reduction in frond damage not sustained by 1988.	Native	160, 169
<i>Oryctes rhinoceros</i> (L.); Asiatic or Coconut rhinoceros beetle	<i>Oryctes rhinoceros nudivirus (OrNV)</i> [= <i>Rhabdionvirus oryctes</i> (Huger); = <i>Baculovirus oryctes</i> Huger]; (Nudiviridae: <i>Alphanudivirus</i>)	SAMOA (Western Samoa)	1967	(<i>ex Malaysia</i>) Established in 1 year and spread. Between 1973-75, adult infection decreased from 63 to 35% and although total population density also declined, damage was noticed again. Virus was re-released 1975-1978 with a resulting decline in damage. 40 years later, in some areas, heavy palm damage suggests a second control breakdown.	Introduced	17, 80, 89, 115, 116, 184, 205
		TOKELAU (in the Pacific)	1967	(<i>ex Malaysia</i>) Released on Nukunonu Atoll. Established and by 1973 39% of beetles infected and only 1.5-6.5% of palm fronds damaged.	Introduced	17, 184, 207

PEST ORDER: FAMILY Target pest species	Biological control agent; (Family: <i>Genus</i>)	Release country or region	Year of release	(<i>Source of biological control agent</i>) Results from introduction	Pest origin	References
COLEOPTERA: SCARABAEIDAE (continued)						
<i>Oryctes rhinoceros</i> (L.) (continued)	<i>Oryctes rhinoceros nudivirus</i> (OrNV) (continued)	FIJI	1970-74	(<i>ex Samoa</i>) Established and by 1974 57-68% of beetles infected. Damage decreased significantly 12-18 months after virus establishment.	Introduced	15, 16, 17, 184
		PALAU (in Micronesia)	1970	(<i>ex Samoa</i>) Established on Babeldaob Island, controlling beetles.	Introduced	167, 184
			1983	(<i>ex Samoa</i>) Released on Peleliu Island and "other places where beetle problems were evident," resulting in beetle control.	Introduced	167
		WALLIS ISLAND (in the Pacific)	1970-71	(<i>ex Samoa</i>) Established; < 2 months after release spread over entire island. In 1 year beetle populations decreased by 60-80% and damage decreased by 82%. Average number infested palms reduced from 60% in 1967 to 20% in 1981.	Introduced	17, 64, 74, 184
		TONGA (in Polynesia)	1970-71	(<i>ex Samoa</i>) Released in Tongatapu. Established, epizootics developed in 5 months and virus spread at 2-3 km/month, beetles and damage reduced. After 7 years, 84% of adult beetles infected throughout population and damage remained low (< 5% of palm crowns surveyed).	Introduced	184, 201, 202
		MAURITIUS (in the Indian Ocean)	1970-72	(<i>ex Samoa</i>) Established, beetle populations declined sharply from 1970. At least through 1976-77, damage reduced by 60-95%.	Introduced	17, 134
		AMERICAN SAMOA	1972	(<i>ex Samoa</i>) Established, virus spread 0.8-1.6 km/month and damage declined.	Introduced	17, 184

PEST ORDER: FAMILY Target pest species	Biological control agent; (Family: <i>Genus</i>)	Release country or region	Year of release	(<i>Source of biological control agent</i>) Results from introduction	Pest origin	References
COLEOPTERA: SCARABAEIDAE (continued)						
<i>Oryctes rhinoceros</i> (L.) (continued)	<i>Oryctes rhinoceros nudivirus</i> (OrNV) (continued)	JAVA (Indonesia)	1976-80	(<i>ex Sumatra, Indonesia</i>) Released in the Province of Central Java. Clear reduction of damage in next 3 years (and not in untreated areas), but no sweeping spread. 1987 survey: low infection in release and untreated areas; suspected virus and beetle resistance present before 1976.	Native	135, 206, 208
		PAPUA NEW GUINEA	1978-79	(<i>ex Samoa</i>) Released on 3 islands. Established at nearly all sites, spread at 1 km/month.	Introduced	62
		INDIA: Minicoy Island	1983-84	(<i>ex Kerala, India</i>) Released on Minicoy Island. Established within 9 months, pest suppressed to low levels and damage reduced. Pest remained at low levels 3.5 years after release.	Native	130
		MALDIVES (in the Indian Ocean)	1984-85	(<i>ex Philippines, Tanzania, and Malaysia</i>) Established and caused highly significant reduction in palm damage on most islands where released. Different strains released and one strain (X2B) consistently yielded better infection and pest reduction.	Native	37, 209
		INDIA: Andaman Islands	1987	(<i>ex Kerala, India</i>) Released at 4 locations on Andaman Islands. Palm damage reduced by 90% within 43 months of release, large reduction in numbers of adults and numbers of breeding sites. Virus spread at 1 km/year. By 1996, beetle populations remained at low levels.	Native	90
		INDIA: Lakshadweep	1988	(<i>ex Kerala, India</i>) Released on Andrott (Androth) Island. Successful introduction. In 1990, coconut palm crop damage measurably less and virus incidence > 60%.	Native	61

TABLE A: EXOTIC VIRUSES RELEASED, BY TARGET PEST

PEST ORDER: FAMILY Target pest species	Biological control agent; (Family: Genus)	Release country or region	Year of release	(Source of biological control agent) Results from introduction	Pest origin	References
COLEOPTERA: SCARABAEIDAE (continued)						
<i>Oryctes rhinoceros</i> (L.) (continued)	<i>Oryctes rhinoceros nudiviruses</i> (OrNV) (continued)	OMAN	1989	(source unknown) Established. Levels of damage steadily declined and 6 years later, only 4-6% of palm fronds were damaged by beetles.	Introduced	95, 96
<i>Scapanes australis</i> (Boisduval); Melanesian rhinoceros beetle	<i>Oryctes rhinoceros nudiviruses</i> (OrNV) [= <i>Rhabdionvirus oryctes</i> (Huger); = <i>Baculovirus oryctes</i> Huger]; (Nudiviridae: <i>Alphanudivirus</i>)	SOLOMON ISLANDS (in the Pacific)	1978-79	(ex Fiji) Released in plantations on New Georgia Island and Kolombangara Island (Western Province), Guadalcanal Island (Guadalcanal Province). Some reduction in host population next year, possible decline in damage, but not consistently.	Native	179, 187
LEPIDOPTERA: ZYGAENIDAE						
<i>Harrisina brillians</i> Barnes & McDunnough; Western grapeleaf skeletonizer	<i>Harrisina brillians granulovirus</i> (HbGV); (Baculoviridae: <i>Betabaculovirus</i>)	USA: California	1981-82	(ex Mexico and Arizona USA) Released in Tulare County in central California. Established; epizootics develop in high density host populations. Overall, lowers general equilibrium density of host populations.	Introduced	182
LEPIDOPTERA: EREBIDAE						
<i>Anticarsia gemmatalis</i> Hübner; Velvetbean caterpillar	<i>Anticarsia gemmatalis multiple nucleopolyhedrovirus</i> (AgMNPV); (Baculoviridae: <i>Alphabaculovirus</i>)	USA: South Carolina	1979-80	(ex Santa Catarina, Brazil) 59-86% infection the season of release but no infections found 1 year after release.	Native	10, 27
		USA: Louisiana	1990-91	(ex Brazil) Released in soybean fields. Established, causing 25-100% infection the year of release and 4-49% infection for years 2-4 after release, even in rotated fields.	Native	54
<i>Lymantria dispar</i> (L.); Gypsy moth	<i>Lymantria dispar multiple nucleopolyhedrovirus</i> (LdMNPV); (Baculoviridae: <i>Alphabaculovirus</i>)	SARDINIA	1972	(ex Serbia, Yugoslavia) Established; high levels of larval mortality year of release, >40% infection the next year and spread over 300 hectares.	Native	114

PEST ORDER: FAMILY Target pest species	Biological control agent; (Family: <i>Genus</i>)	Release country or region	Year of release	(<i>Source of biological control agent</i>) Results from introduction	Pest origin	References
LEPIDOPTERA: EREBIDAE (continued)						
<i>Lymantria monacha</i> L.; Nun moth	<i>Lymantria monacha nucleopolyhedrovirus</i> (LmNPV); (Baculoviridae: <i>Alphabaculovirus</i>)	DENMARK	1973-74	(<i>ex Sweden and West Germany</i>) Released in Silkeborg in 1973: 90% infection year of release and, in 1974, no serious defoliation within and directly around virus-release stands while insecticides had to be applied to other areas. In 1975, no virus was found in the few larvae collected. Released in Grindsted in 1974: the population collapsed that year but it is suggested that other factors, including the native virus, played important parts.	Native	210
LEPIDOPTERA: NOCTUIDAE						
<i>Trichoplusia ni</i> (Hübner); Cabbage looper	<i>Trichoplusia ni nucleopolyhedrovirus</i> (TnNPV); (Baculoviridae: <i>Alphabaculovirus</i>)	COLOMBIA	1970	(<i>ex California USA</i>) Persisted after release, controlling subsequent pest generations.	Introduced	19, 39
<i>Pseudoplusia includens</i> (Walker); Soybean looper	<i>Pseudoplusia includens single nucleopolyhedrovirus</i> (PsinSNPV); (Baculoviridae: <i>Alphabaculovirus</i>)	USA: Louisiana	1975-77	(<i>ex Guatemala</i>) Released in soybean fields. Established; 38-63% infection 12-15 years after introduction.	Native	55
<i>Agrotis segetum</i> (Denis & Schiffermüller); Turnip moth	<i>Agrotis segetum granulovirus (AsGV)</i> ; (Baculoviridae: <i>Betabaculovirus</i>)	DENMARK	1975-80	(<i>ex Austria</i>) Released in Lammefjord. Caused 65-70% reduction in damage soon after release and thought to have spread 10 m from release. One year after release, ca. 99% of infectivity of virus applied to soils had been lost.	Native	211, 212, 217
HYMENOPTERA: DIPRIONIDAE						
<i>Gilpinia hercyniae</i> (Hartig) [= <i>Diprion hercyniae</i> Hartig]; European spruce sawfly	<i>Gilpinia hercyniae nucleopolyhedrovirus</i> (GhNPV); (Baculoviridae: <i>Gammabaculovirus</i>)	CANADA: Newfoundland	1943-45	(<i>ex mainland Canada</i>) Established and by 1946 reported as prevalent over considerable areas surrounding release areas.	Introduced	6, 119

PEST ORDER: FAMILY Target pest species	Biological control agent; (Family: <i>Genus</i>)	Release country or region	Year of release	(<i>Source of biological control agent</i>) Results from introduction	Pest origin	References
HYMENOPTERA: DIPRIONIDAE (continued)						
<i>Gilpinia hercyniae</i> (Hartig) (continued)	<i>Gilpinia hercyniae nucleopolyhedrovirus</i> (GhNPV) (continued)	CANADA: Ontario	1950	(<i>ex New Brunswick, Canada</i>) Released in an isolated host population in Sault Ste. Marie, 160 km (100 miles) beyond western distribution of insect. Established and spread rapidly through infested area. Epizootics occurred yearly (1950-1959), hosts kept below economic damage level.	Introduced	24
<i>Neodiprion sertifer</i> (Geoffrey); European pine sawfly	<i>Neodiprion sertifer nucleopolyhedrovirus</i> (NeseNPV); (Baculoviridae: <i>Gammabaculovirus</i>)	CANADA: Ontario	1950+	(<i>ex Sweden</i>) Released in southern Ontario near Strathroy. Over 90% mortality 14 days after release and virus persisted. Widely distributed for release in pine plantations, e.g., one introduction in 1951 controlled an infestation over 100 acres within 3 years. After introduction, this virus replaced insecticides for controlling hosts and provided long term control. Today, host is a minor pest of plantations and ornamentals but occasionally can increase locally as natural spread and effectiveness of the virus is much reduced at low host densities.	Introduced	23, 40, 45, 119
		USA: New Jersey	1951-52	(<i>ex Canada</i>) Established and spread (ca. 300 m from individual trees after release). Released also in 1952. Provided complete control.	Introduced	45
		USA: Illinois	1952	(<i>ex New Jersey USA; originally Canada</i>) By 19 days after treatment, 82-100% control. In 1953, spread was up to 80 m from treated area. Excellent control achieved.	Introduced	20, 45
		USA: Indiana	1953	(<i>ex Canada</i>) Reported as maintaining adequate control over several years through recurring epizootics after establishment.	Introduced	168
		UK: SCOTLAND	1961	(<i>ex Canada</i>) 85% of colonies had infected individuals 24 days after release, resulting in very good control. In 1962, found to persist in treated areas but minimal spread.	Native	41, 163

TABLE B: Exotic Bacteria Released, by Target Pest

PEST ORDER: FAMILY Target pest species	Biological control agent; (Family)	Release country or region	Year of release	(Source of biological control agent) Results from introduction	Pest origin	References
COLEOPTERA: SCARABAEIDAE						
<i>Cochliotus melolonthoides</i> (Gerstaecker)	<i>Paenibacillus popilliae</i> (Dutky); (Paenibacillaceae)	TANZANIA	1968	(ex USA, probably) Strain from Japanese beetle, <i>Popillia japonica</i> Newman. Seemed to become established but this is not certain due to presence of an indigenous milky disease.	Native	63
<i>Oryctes rhinoceros</i> (L.); Asiatic or Coconut rhinoceros beetle	<i>Paenibacillus popilliae</i> (Dutky); (Paenibacillaceae)	PALAU (in Micronesia)	1951	(ex USA) Strain from Japanese beetle, <i>Popillia japonica</i> Newman. Not recovered after release.	Introduced	184
		AMERICAN SAMOA	1957	(ex USA) Strain from Japanese beetle, <i>Popillia japonica</i> Newman. Not recovered after release.	Introduced	184
<i>Papuana huebneri</i> (Halmahera); Taro beetle	<i>Paenibacillus popilliae</i> (Dutky); (Paenibacillaceae)	KIRIBATI (in the Pacific)	1995-96	(ex Papua New Guinea and Solomon Islands) Released on South Tarawa. Isolate from Papua New Guinea (type A1) caused infections 1 year after release.	Introduced	188
<i>Popillia japonica</i> (Dutky); Japanese beetle	<i>Paenibacillus popilliae</i> (Dutky); (Paenibacillaceae)	AZORES: Terceira Island	1990-91	(ex USA) Did not appear to be effective. Establishment is questionable.	Introduced	106, 122
<i>Schizonycha</i> sp.	<i>Paenibacillus popilliae</i> (Dutky); (Paenibacillaceae)	KENYA	1956	(ex USA) A and B strains from Japanese beetle, <i>Popillia japonica</i> Newman. Not recovered after release.	Native	63

TABLE C: Exotic Fungi Released, by Target Pest (see also page 58)

PEST ORDER: FAMILY Target pest species	Biological control agent; (Order: Family)	Release country or region	Year of release	(Source of biological control agent) Results from introduction	Pest origin	References
ORTHOPTERA: ACRIDIDAE						
<i>Melanoplus sanguinipes</i> (F.); Migratory grasshopper	<i>Entomophaga grylli</i> (Fresenius) Batko, pathotype III; (Entomophthorales: Entomophthoraceae)	USA: Alaska	1990	(ex Australia) No establishment.	Native	28, 161
<i>Melanoplus bivittatus</i> (Say); Two-striped grasshopper; <i>M. sanguinipes</i> (F.); Migratory grasshopper; <i>Camnula pellucida</i> Scudder; Clearwinged grasshopper; and other spp.	<i>Entomophaga grylli</i> (Fresenius) Batko, pathotype III; (Entomophthorales: Entomophthoraceae)	USA: North Dakota	1989-91	(ex Australia) Isolate chosen based on biology, similarity of climates and ability to infect species in both Oedipodinae and Melanopliinae, but not <i>Hesperotettix viridis</i> (Scudder). Populations of some species declined in 1991-92 with 23% infection in 1992 at < 1 km from release, 1.7% in 1993 and no infection in 1994 when host populations were low. Long term establishment questionable.	Native	22, 28, 29
<i>Phaulacridium vittatum</i> (Sjöstedt); Wingless grasshopper	<i>Entomophaga grylli</i> (Fresenius) Batko, pathotype I; (Entomophthorales: Entomophthoraceae)	AUSTRALIA	1984	(ex Arizona USA) Released near Canberra. Epizootics did not occur and permanent establishment questioned, efficacy unlikely.	Native	125
HEMIPTERA: CERCOPIDAE						
<i>Aeneolamia flavilatera</i> (Urich)	<i>Metarhizium anisopliae</i> (Metschnikoff) Sorokin; (Hypocreales: Clavicipitaceae)	GUYANA (in South America)	1944	(ex Trinidad) Introduced by releasing infected adult froghoppers. Established, considered unsuccessful for control but < 1 year later abundant infections ca. 32 km away. Unknown whether this was due to introduced or indigenous fungus.	Native	33

PEST ORDER: FAMILY Target pest species	Biological control agent; (Order: Family)	Release country or region	Year of release	(Source of biological control agent) Results from introduction	Pest origin	References
HEMIPTERA: CICADELLIDAE						
<i>Empoasca fabae</i> (Harris); Potato leafhopper	<i>Zoophthora</i> (= <i>Erynia</i>) <i>radicans</i> (Brefeld) Batko; (Entomophthorales: Entomophthoraceae)	USA: Illinois	1984	(ex Brazil) No establishment.	Introduced	77, 120
		USA: New York	1990-91	(ex Serbia) Released in central New York State. Field infection confirmed but monitoring not continued in subsequent years.	Introduced	77
Unspecified species of leafhopper	Unidentified fungus	USA: Hawaii	1906	(ex Australia and Fiji) Fungus found infecting leafhopper eggs at source. Establishment not confirmed.	Unknown	147
HEMIPTERA: APHIDIDAE						
<i>Aphis gossypii</i> Glover; Cotton aphid	<i>Neozygites fresenii</i> (Nowakowski) Batko; (Neozygitales: Neozygitaceae)	USA: California	1994-95	(ex Arkansas USA) Released in San Joaquin Valley. Cycling during release seasons with infection levels that would have initiated epizootics in Arkansas but epizootics did not occur in California. Persisted until end of release seasons but not recovered 1997-2001, so long term establishment questionable.	Introduced	60, 181
<i>Diuraphis noxia</i> Kurdjumov; Russian wheat aphid	<i>Zoophthora radicans</i> (Brefeld) Batko; (Entomophthorales: Entomophthoraceae)	USA: Idaho	1992	(ex Serbia) To release, parasitoids <i>Aphelinus asychis</i> (Walker) were inoculated or sporulating cultures were added to colonies. The fungus only made resting spores within cadavers and no subsequent surveys were conducted to evaluate establishment.	Introduced	138, 156
<i>Macrosiphum solanifolii</i> (Ashmead); Potato aphid	Probably in <i>Lecanicillium</i> (= <i>Verticillium</i>) <i>lecanii</i> species complex [Reported as <i>Acrostalagmus</i> sp.]; (Hypocreales: Cordycipitaceae)	USA: Maine	1955	(ex Hawaii USA) Diseased aphids found 3 weeks after release and one infected specimen found in 1958. Unknown if permanently established.	Native	170, 171

PEST ORDER: FAMILY Target pest species	Biological control agent; (Order: Family)	Release country or region	Year of release	(Source of biological control agent) Results from introduction	Pest origin	References
HEMIPTERA: APHIDIDAE (continued)						
<i>Metopolophium dirhodum</i> (Walker); Rose-grain aphid; and other cereal aphid spp.	<i>Pandora neoaphidis</i> (Remaudière & Hennebert) Humber; (Entomophthorales: Entomophthoraceae)	BELGIUM	1982	(<i>ex Brazil</i>) Isolate chosen due to good <i>in vitro</i> growth. Limited transmission in field after release, probably because few conidia are produced by isolate. Limited transmission suggests poor chance of establishment.	Native	110
<i>Therioaphis maculata</i> (Buckton); Spotted alfalfa aphid	<i>Zoophthora radicans</i> (Brefeld) Batko [= <i>Entomophthora sphaerosperma</i> Fresenius]; (Entomophthorales: Entomophthoraceae)	AUSTRALIA: New South Wales	1979	(<i>ex Israel</i>) Isolate chosen in part due to similar climate. Became widely distributed in New South Wales and southern Queensland, causing epizootics in late summer/autumn; only the first aphid outbreaks in spring likely to escape infection.	Introduced	126, 127, 128
HEMIPTERA: ALEYRODIDAE						
<i>Aleurodicus cocois</i> (Curtis); Coconut whitefly; and <i>Aleurothrixus floccosus</i> (Maskell); Woolly whitefly	<i>Aschersonia aleyrodinis</i> Webber; (Hypocreales: Clavicipitaceae)	VIRGIN ISLANDS	Before 1920	(<i>source unknown</i>) No establishment due to high winds and drought.	Native?	195
<i>Dialeurodes</i> sp.; Whitefly	<i>Aschersonia aleyrodinis</i> Webber; (Hypocreales: Clavicipitaceae)	BERMUDA	1926	(<i>ex Florida USA</i>) Establishment and persistence not reported.	Unknown	143
<i>Singhiella citrifolii</i> (Morgan) [= <i>Dialeurodes citrifolii</i> Morgan]; Cloudywinged whitefly	<i>Aschersonia goldiana</i> Saccardo & Ellis; (Hypocreales: Clavicipitaceae)	BERMUDA	1924	(<i>ex Florida USA</i>) Considered established in 1925 but only provided efficient control in well-shaded situations.	Introduced	141, 142

PEST ORDER: FAMILY Target pest species	Biological control agent; (Order: Family)	Release country or region	Year of release	(Source of biological control agent) Results from introduction	Pest origin	References
HEMIPTERA: ALEYRODIDAE (continued)						
<i>Dialeurodes citri</i> (Ashmead); Citrus whitefly	<i>Aschersonia</i> spp.; (Hypocreales: Clavicipitaceae)	USSR: AZERBAIJAN and GEORGIA	1960-64	(<i>ex China, Cuba, India, Japan, Trinidad, USA, and Vietnam</i>) Multiple species, at least 11 strains, were released in citrus plantations; no information on which became established. About 80% mortality of nymphs under favorable conditions and fungus spread to new plantations. The most aggressive was <i>A. placenta</i> Berkeley & Broome from Vietnam and China: up to 90% nymphal mortality in Adzharia, Georgia in favorable weather, but inhibited by drought. In 1980-84, in areas of Georgia and Azerbaijan where large complexes of natural enemies occurred in citrus plantations (including <i>Aschersonia</i> spp.), the pest was kept below the economic threshold.	Introduced	88, 117, 155, 159
Unspecified species of whitefly	Unidentified fungus	USA: Hawaii	1909	(<i>ex Florida USA</i>) One species released. Results not reported.	Unknown	104
HEMIPTERA: COCCIDAE						
<i>Coccus viridis</i> (Green); Green scale	Unidentified fungus [possibly in <i>Lecanicillium</i> (= <i>Verticillium</i>) <i>lecanii</i> species complex]; (Hypocreales: Cordycipitaceae)	USA: Hawaii	1928 or before	(<i>ex Florida USA</i>) Established and provided effective control.	Introduced	87, 185
<i>Coccus viridis</i> (Green); Green scale; <i>Eucalymnatus tessellatus</i> (Signoret); Tesselated scale; and <i>Ceroplastes rubens</i> Maskell; Red wax scale	<i>Lecanicillium lecanii</i> (Zimmerman) Gams & Zare [= <i>Verticillium lecanii</i> (Zimmerman); = <i>Cephalosporium lecanii</i> Zimmerman]; (Hypocreales: Cordycipitaceae)	SEYCHELLES (in the Indian Ocean)	1911	(<i>ex Sri Lanka (Ceylon)</i>) Established and largely controlled scale populations.	Introduced	3

PEST ORDER: FAMILY Target pest species	Biological control agent; (Order: Family)	Release country or region	Year of release	(Source of biological control agent) Results from introduction	Pest origin	References
HEMIPTERA: COCCIDAE (continued)						
<i>Coccus viridis</i> (Green); Green scale; and other Lecaniine scale spp.	<i>Lecanicillium lecanii</i> (Zimmerman) Gams & Zare [= <i>Verticillium lecanii</i> (Zimmerman); = <i>Cephalosporium lecanii</i> Zimmerman]; (Hypocreales: Cordycipitaceae)	SEYCHELLES (in the Indian Ocean)	Before 1933	(ex India) Well established on lecaniine scales, especially <i>Coccus viridis</i> on coffee, and spread widely.	Introduced	178
Unspecified species of coccid scale	Unidentified fungi	USA: Hawaii	1897	(source unreported) Two species released. Established and spread over most parts of the islands.	Unknown	102
HEMIPTERA: DIASPIDIDAE						
<i>Aonidiella aurantii</i> (Maskell); California red scale	<i>Fusarium coccophilum</i> (Desmazieres) Wollenweber & Reinking [= <i>Fusarium episphaerea</i> f. <i>coccophila</i> Tul.]; teleomorph = <i>Nectria flammea</i> (Tulasne & Tulasne) Dingley; (Hypocreales: Nectriaceae)	ARGENTINA	1900	(ex USA) Established and occasionally caused up to 90% mortality in northeastern and northwestern regions.	Introduced	38
<i>Aspidiotus destructor</i> Signoret; Coconut scale	<i>Fusarium juruanum</i> P. Hennings [= <i>Pseudomicrocera henningsii</i> (Koord.) Petch]; (Hypocreales: Nectriaceae)	SEYCHELLES (in the Indian Ocean)	1929	(ex Sierra Leone, west Africa) Did not establish.	Introduced	46

PEST ORDER: FAMILY Target pest species	Biological control agent; (Order: Family)	Release country or region	Year of release	(Source of biological control agent) Results from introduction	Pest origin	References
HEMIPTERA: DIASPIDIDAE (continued)						
<i>Lepidosaphes beckii</i> (Newman) [= <i>Cornuaspis beckii</i> (Newman)]; Purple or Mussel scale	<i>Fusarium coccophilum</i> (Desmazieres) Wollenweber & Reinking [= <i>Sphaerostilbe coccophila</i> Tul.]; teleomorph = <i>Nectria flammea</i> (Tulasne & Tulasne) Dingley; (Hypocreales: Nectriaceae)	USA: Hawaii	1905 or before	(ex Florida USA) Established and locally abundant but control only partial.	Introduced	103
		BERMUDA	1926	(ex Florida USA) Establishment and persistence not reported.	Introduced	143
		BERMUDA	1926	(ex Florida USA) Establishment and persistence not reported.	Introduced	143
		BERMUDA	1926	(ex Florida USA) Released on infested citrus trees throughout the island. Found already present on <i>L. beckii</i> at one site. Establishment and persistence not reported.	Introduced	143
<i>Quadraspidiotus perniciosus</i> (Comstock) [= <i>Aspidiotus perniciosus</i> Comstock]; San Jose scale	<i>Fusarium coccophilum</i> (Desmazieres) Wollenweber & Reinking [= <i>Sphaerostilbe coccophila</i> Tul.]; teleomorph = <i>Nectria flammea</i> (Tulasne & Tulasne) Dingley; (Hypocreales: Nectriaceae)	USA: California	1897	(ex Florida USA) As a result of this introduction, or a native fungus, scale nearly exterminated in southern California.	Introduced	198
		USA: New Jersey	1897	(ex Florida USA) Established, overwintered, with abundant infection the following September but this pathogen alone failed to provide adequate control.	Introduced	172, 173
		USA: Illinois	1898	(ex Florida USA) Released by tying twigs with infected scales to trees. Overwintered and many scales infected but healthy scales still abundant. Hypothesized this fungus could add to effects of other natural enemies to provide a permanent check of scale populations but the level of fungus activity would depend on rainfall levels.	Introduced	52

PEST ORDER: FAMILY Target pest species	Biological control agent; (Order: Family)	Release country or region	Year of release	(Source of biological control agent) Results from introduction	Pest origin	References
THYSANOPTERA: THIRIPIDAE						
<i>Thrips tabaci</i> Lindeman; Onion thrips	<i>Neozygites parvispora</i> (MacLeod & Carl) Remaudière & Keller; (Neozygiales: Neozygiteaceae)	BARBADOS	1973-76	(ex Switzerland) Released in onion field but no establishment.	Introduced	33
COLEOPTERA: SCARABAEIDAE						
<i>Adoretus tenuimaculatus</i> Waterhouse	<i>Metarhizium anisopliae</i> (Metschnikoff) Sorokin; (Hypocreales: Clavicipitaceae)	FIJI	Before 1918	(source unknown) Some signs that this fungus acted as a check on the beetles.	Introduced	101
<i>Alissonotum impressicolle</i> Arrow	<i>Metarhizium anisopliae</i> (Metschnikoff) Sorokin; (Hypocreales: Clavicipitaceae)	TAIWAN	1914	(ex Hawaii USA) Numbers of scarabs greatly reduced in fields where spores were released.	Native	199, 200
<i>Dermolepida albohirtum</i> (Waterhouse); Greyback cane beetle	<i>Metarhizium anisopliae</i> (Metschnikoff) Sorokin; (Hypocreales: Clavicipitaceae)	AUSTRALIA: Queensland	About 1914	(ex Samoa) Released in Queensland but before release, had already been found infecting this host in Queensland. Post release, at times considerable numbers of grubs of intended host and <i>Rhabdoscelus obscurus</i> (Boisduval), the New Guinea sugarcane weevil, killed by this fungus.	Native	196
<i>Lepidiota pruinosa</i> Wied., and <i>Leucopholis irrorata</i> Chevrolat; white grubs in sugar cane	<i>Metarhizium anisopliae</i> (Metschnikoff) Sorokin; (Hypocreales: Clavicipitaceae)	PHILIPPINES	1928	(ex Queensland, Australia) Not effective control and "undoubtedly already present."	Native	162
<i>Lepidiota</i> sp., <i>Anoplognathus</i> sp., and other spp.; white grubs in sugar cane	<i>Beauveria brongniartii</i> (Saccardo) Petch [= <i>Botrytis tenella</i> Sacc.]; (Hypocreales: Cordycipitaceae)	AUSTRALIA	1894-95	(ex France) Released in Queensland and New South Wales. Negative results in New South Wales after dissemination.	Unknown	196

PEST ORDER: FAMILY Target pest species	Biological control agent; (Order: Family)	Release country or region	Year of release	(Source of biological control agent) Results from introduction	Pest origin	References
COLEOPTERA: SCARABAEIDAE (continued)						
<i>Oryctes rhinoceros</i> (L.); Asiatic or Coconut rhinoceros beetle	<i>Metarhizium anisopliae</i> (Metschnikoff) Sorokin; (Hypocreales: Clavicipitaceae)	SAMOA (Western Samoa)	1939	(ex Java, Indonesia) This fungal species recovered after release but whether it was the introduced strain or a native strain is uncertain.	Introduced	184
		WALLIS ISLAND (in the Pacific)	1952	(ex Argentina) Results from release unknown.	Introduced	184
		TOKELAU (in the Pacific)	1967	(ex Samoa) Results from release unknown.	Introduced	184
		TONGA (in Polynesia)	1969	(ex Samoa) High levels of infection directly after release, infections still present 3 years later but prevalence extremely low.	Introduced	184, 201
<i>Papuana huebneri</i> (Halmahera); Taro beetle	<i>Metarhizium anisopliae</i> (Metschnikoff) Sorokin; (Hypocreales: Clavicipitaceae)	KIRIBATI (in the Pacific)	1976	(source unknown) Released on southern Tarawa by Latch. Establishment not confirmed.	Introduced	124
			1995	(ex Papua New Guinea) Released on southern Tarawa. Persisted in soil through 2003, spread and exerted some control.	Introduced	124, 188
<i>Phyllophaga smithi</i> (Arrow) [= <i>Lachnosterna</i> <i>smithi</i> (Arrow); = <i>Clemora smithi</i> (Arrow); = <i>Phytalus smithi</i> Arrow]; white grub in sugar cane	<i>Beauveria bassiana</i> (Balsamo) Vuillemin [= <i>Beauveria densa</i> (Link) Vuillemin]; (Hypocreales: Cordycipitaceae)	MAURITIUS (in the Indian Ocean)	1932	(ex UK) Unknown isolate from Imperial Bureau of Mycology. Host population gradually declined and diseases may have played a part.	Introduced	63, 131, 132, 133
	<i>Metarhizium anisopliae</i> (Metschnikoff) Sorokin; (Hypocreales: Clavicipitaceae)		1932	(ex UK) Unknown isolate from Imperial Bureau of Mycology. Host population gradually declined and diseases may have played a part.	Introduced	63, 131, 132, 133

PEST ORDER: FAMILY Target pest species	Biological control agent; (Order: Family)	Release country or region	Year of release	(Source of biological control agent) Results from introduction	Pest origin	References
COLEOPTERA: CURCULIONIDAE						
<i>Otiorhynchus nodosus</i> (Müller), and <i>O. arcticus</i> (Fabricius)	<i>Metarhizium anisopliae</i> (Metschnikoff) Sorokin; (Hypocreales: Clavicipitaceae)	ICELAND	2003	(ex Havnardalur, Faroe Islands) Released in eroded areas in Haukadalur. Establishment unknown. Heathland soil in Haukadalur in 1999 found to have <i>M. anisopliae</i> in 40% of samples.	Native	139, 140
<i>Sitona discoideus</i> Gyllenhal; Sitona weevil	<i>Beauveria bassiana</i> (Balsamo) Vuillemin; (Hypocreales: Cordycipitaceae)	AUSTRALIA	1984	(ex Montpellier, France) Released in southern Australia. No infections ever found.	Introduced	5
DIPTERA: CULICIDAE						
<i>Aedes polynesiensis</i> Marks	<i>Coelomomyces stegomyiae</i> Keilin; (Blastocladales: Coelomomycetaceae)	TOKELAU (in the Pacific)	1958	(ex Singapore) Released on Nukunonu Atoll. Established, by 1963 infected larvae found in 13 of 35 habitats.	Native	75, 107
LEPIDOPTERA: EREBIDAE						
<i>Lymantria dispar</i> (L.); Gypsy moth	<i>Entomophaga maimaiga</i> Humber, Shimazu & Soper; (Entomophthorales: Entomophthoraceae)	USA: Massachusetts	1910-11	(ex Nishigahara, Tokyo Prefecture, Japan) Released in Boston area. In 1911 found to be not established.	Introduced	177
		USA: New York	1985	(ex Ishikawa Prefecture, Japan) Released in Allegany State Park in southwestern New York State. No transmission to host population detected. Not established.	Introduced	67, 69
		USA: Virginia	1986	(ex Ishikawa Prefecture, Japan) Released in Shenandoah National Park in northern Virginia. Very low transmission to host population. Not established.	Introduced	67, 69

PEST ORDER: FAMILY Target pest species	Biological control agent; (Order: Family)	Release country or region	Year of release	(Source of biological control agent) Results from introduction	Pest origin	References
LEPIDOPTERA: EREBIDAE (continued)						
<i>Lymantria dispar</i> (L.) (continued)	<i>Entomophaga maimaiga</i> Humber, Shimazu & Soper (continued)	USA: Virginia, West Virginia, Maryland, Pennsylvania	1991-92	(ex Massachusetts and New York USA) Soil with resting spores released along leading edge of <i>L. dispar</i> spread, in Virginia, West Virginia, Maryland, western Pennsylvania. Epizootics developed in 1992 in the majority of 1991 release sites, and infections also detected in most control plots; <i>E. maimaiga</i> had spread rapidly south and west to edge of host distribution.	Introduced	68
		USA: Michigan	1991-92	(ex Massachusetts USA) Released as resting spores in soil and as cadavers from inoculated larvae, at sites along the leading edge of <i>L. dispar</i> distribution. One site had infected larvae in 1991; infection also low in 1992; in 1993 infection from 20-99% at release sites and in some control sites, and host populations declined at release sites.	Introduced	174
		BULGARIA	1996	(ex Connecticut USA) Released in Levishte, in northeastern Bulgaria. No infection in 1997.	Native	150
			1999	(ex Massachusetts USA) Released in Karlovo, in central Bulgaria. Established but negligible control.	Native	152
			2000	(ex Connecticut USA) Released in Levishte. Infections found in 2002, 2003 and 2004 and fungus was subsequently redistributed within Bulgaria. By 2013 found in nearby countries (including Serbia, Croatia, Hungary, Slovakia, Bosnia and Herzegovina, western Turkey, Greece, and Macedonia). Fungus assumed to have spread from Bulgarian introductions.	Native	58, 150, 216
	RUSSIA: Novosibirsk region	2002	(ex Virginia USA) Establishment not confirmed.	Native	4	

PEST ORDER: FAMILY Target pest species	Biological control agent; (Order: Family)	Release country or region	Year of release	(Source of biological control agent) Results from introduction	Pest origin	References
SUBCLASS ACARI: ORDER PROSTIGMATA: ERIOPHYIDAE						
<i>Eriophyes sheldoni</i> (Ewing); Citrus bud mite	<i>Hirsutella thompsonii</i> Fisher var. <i>vinacea</i> Samson, McCoy & O'Donnell; (Hypocreales: Ophiocordycipitaceae)	ARGENTINA	1985	(ex North Carolina USA) Released on lemon trees in Tucuman. Initially 92% decrease in mites but persistence unknown.	Introduced	175, 176
<i>Eriophyes sheldoni</i> (Ewing); Citrus bud mite; and <i>Phyllocoptruta oleivora</i> (Ashmead); Citrus rust mite	<i>Hirsutella thompsonii</i> Fisher var. <i>synnematos</i> Samson, McCoy & O'Donnell; (Hypocreales: Ophiocordycipitaceae)	ARGENTINA	1985	(ex Zimbabwe) Released in Tucuman. About 50% infection for both mites after release but persistence unknown.	Introduced	175, 176
SUBCLASS ACARI: ORDER PROSTIGMATA: TETRANYCHIDAE						
<i>Mononychellus tanajoa</i> (Bondar); Cassava green mite	<i>Neozygites tanajoe</i> Delalibera, Hajek & Humber (prev. referred to as <i>Neozygites floridana</i> (Weiser & Muma) Remaudière & Keller); (Neozygiales: Neozygiteaceae)	BENIN (in west Africa)	1998-99	(ex northeastern Brazil) Established, epizootics occurring in 2002 and 2003 at release sites. Molecular probes developed to confirm that epizootics were caused by exotic, the introduced pathogen, rather than a closely related native strain.	Introduced	42, 79

TABLE D: Exotic Microsporidia Released, by Target Pest

PEST ORDER: FAMILY Target pest species	Biological control agent; (Clade)	Release country or region	Year of release	(Source of biological control agent) Results from introduction	Pest origin	References
ORTHOPTERA: ACRIDIDAE						
<i>Dichroplus maculipennis</i> (Blanchard), <i>D. elongatus</i> (Giglio-Tos), <i>D. pratensis</i> Bruner, and <i>Scotussa lemniscata</i> Stål	<i>Paranosema locustae</i> (Canning) [= <i>Nosema locustae</i> Canning; = <i>Antonospora locustae</i> (Canning)]; (Clade 2)	ARGENTINA	1978-82	(ex Idaho USA) Released in central Argentina. Principal targets in Melanoplinae. Established and, in 1994-95, found 75 km from release sites. Epizootics occur with accompanying host declines but levels of infection in susceptible species usually average < 10%.	Native	109
DIPTERA: CULICIDAE						
<i>Culex pipiens quinquefasciatus</i> Say [= <i>C. pipiens fatigans</i> Wiedemann; = <i>C. fatigans</i> Wiedemann]	<i>Vavraia culicis</i> (Weiser) Weiser [= <i>Pleistophora / Plistophora culicis</i> Weiser]; (Clade 5)	NAURU (in Micronesia)	1967	(ex Lagos, Nigeria) Establishment not confirmed.	Native	107
LEPIDOPTERA: CRAMBIDAE						
<i>Ostrinia nubilalis</i> (Hübner); European corn borer	<i>Nosema pyrausta</i> (Paillot) [= <i>Perezia pyraustae</i> Paillot; = <i>Glugea pyraustae</i> (Paillot)]; (Clade 4, Branch A)	USA: Illinois	Between 1952-60	(ex Iowa USA) Exact release year unknown. Infected larvae distributed at scattered localities throughout Illinois. Disease became prevalent and kept host populations at low levels.	Introduced	43

PEST ORDER: FAMILY Target pest species	Biological control agent; (Clade)	Release country or region	Year of release	(Source of biological control agent) Results from introduction	Pest origin	References
LEPIDOPTERA: EREBIDAE						
<i>Lymantria dispar</i> (L.); Gypsy moth	<i>Nosema portugal</i> Maddox & Vávra [= <i>Microsporidium</i> sp.]; (Clade 4, Branch A)	USA: Maryland	1986	(ex Portugal) Established, low levels of infection in 1987 which persisted for 3 years.	Introduced	91, 92, 121
		USA: Michigan	1992-93	(ex Portugal) Low levels of infection during the season of release, persistence not confirmed.	Introduced	8, 9
	<i>Endoreticulatus schubergi</i> (Zwölfer) A. Cali & El Garhy [Reported as <i>Vavraia</i> sp.]; (Clade 4, Branch B)	USA: Maryland	1986	(ex Portugal) Not established.	Introduced	91, 92, 121
	<i>Nosema lymantriae</i> Weiser; (Clade 4, Branch A)	USA: Illinois	2008, 2010	(ex Bulgaria) Not established.	Introduced	151
<i>Vairimorpha disparis</i> (Timofejeva); (Clade 4, Branch A)	USA: Illinois	2008, 2010	(ex Bulgaria) Not established.	Introduced	151	

TABLE E: Exotic Oomycete Released, by Target Pest

PEST ORDER: FAMILY Target pest species	Biological control agent; (Order: Family)	Release country or region	Year of release	(Source of biological control agent) Results from introduction	Pest origin	References
DIPTERA: CULICIDAE						
<i>Culex tarsalis</i> Coquillett; Western encephalitis mosquito	<i>Lagenidium giganteum</i> Couch; (Lagenidiales: Lagenidiaceae)	USA: California	1972	(ex North Carolina USA) Released in rice fields in Colusa County and irrigated pastures near Hanford, California. Recovered 3 consecutive years but dispersal from inoculation sites minimal.	Native	51, 118, 193

TABLE F: Exotic Nematodes Released, by Target Pest

PEST ORDER: FAMILY Target pest species	Biological control agent; (Order: Family)	Release country or region	Year of release	(Source of biological control agent) Results from introduction	Pest origin	References
ORTHOPTERA: GRYLLOTALPIDAE						
<i>Scapteriscus abbreviatus</i> Scudder, <i>S. borelli</i> Gigli-Tos, and <i>S. vicinus</i> Scudder; Mole crickets	<i>Steinernema scapterisci</i> Nguyen & Smart; (Rhabditida: Steinernematidae)	USA: Florida	1985	(ex Uruguay) Established. Host populations declined by 85-98%, by 1988 infected hosts collected 23 km from release site. Establishment on golf courses not as successful but > 27% reduction in hosts when persisting. <i>S. borelli</i> more susceptible than <i>S. vicinus</i> , but both can be controlled.	Introduced	53, 145
<i>Scapteriscus didactylus</i> (Latreille) and <i>S. abbreviatus</i> Scudder; Mole crickets	<i>Steinernema scapterisci</i> Nguyen & Smart; (Rhabditida: Steinernematidae)	PUERTO RICO	2001-04	(ex Florida USA; originally Uruguay) Establishment confirmed. <i>S. didactylus</i> in Puerto Rico about as susceptible as <i>S. borellii</i> is in Florida, but <i>S. abbreviatus</i> , for unknown reasons, is less susceptible.	Introduced	53, 111
COLEOPTERA: SCARABAEIDAE						
<i>Oryctes rhinoceros</i> (L.); Asiatic or Coconut rhinoceros beetle	<i>Rhabditis</i> sp.; (Rhabditida: Rhabditidae)	FIJI	1954	(ex Sri Lanka (Ceylon)) Results of release not reported.	Introduced	32
			1957	(ex Madagascar) Recovered after release, persistence not confirmed.	Introduced	184
		AMERICAN SAMOA	1957	(ex Madagascar) Results from release unknown.	Introduced	184

PEST ORDER: FAMILY Target pest species	Biological control agent; (Order: Family)	Release country or region	Year of release	(Source of biological control agent) Results from introduction	Pest origin	References
COLEOPTERA: SCARABAEIDAE (continued)						
<i>Oryctes rhinoceros</i> (L.) (continued)	<i>Rhabditis</i> sp. nr. <i>maupasi</i> ; (Rhabdita: Rhabditidae)	SAMOA (Western Samoa)	1957	(ex Sri Lanka (Ceylon)) Results from release unknown.	Introduced	184
		AMERICAN SAMOA	1957	(ex Sri Lanka (Ceylon)) Results from release unknown.	Introduced	184
		WALLIS ISLAND (in the Pacific)	1957	(ex Sri Lanka (Ceylon)) Results from release unknown.	Introduced	184
COLEOPTERA: CURCULIONIDAE						
<i>Sitona discoideus</i> Gyllenhal; Sitona weevil	<i>Heterorhabditis bacteriophora</i> Poinar [= <i>H. heliothidis</i> (Khan, Brooks & Hirschmann)]; (Rhabditida: Heterorhabditidae)	AUSTRALIA	1982	(ex New Zealand) Released in southern Australia. No infections found. This species thought not to occur in Australia when introduced, but now known to have been present, although this is still an example of introduction of an exotic strain.	Introduced	5, 93
DIPTERA: CULICIDAE [listed in order of country of release]						
Anopheline spp. and Culicine spp.	<i>Romanomermis culicivorax</i> Ross & Smith [= <i>Reesimermis nielsenii</i> Tsai & Grundmann]; (Mermithida: Mermithidae)	AZERBAIJAN (USSR)	ca 1990	(source unknown) <i>Aedes caspius</i> (Pallas), <i>Culex modestus</i> Ficalbi, <i>C. theileri</i> Theobald, <i>Uranotaenia unguiculata</i> Edwards first reported as hosts. The nematodes survived drying of up to 2 weeks and survived the winter in some reservoirs. Longer term establishment unknown.	Native	2, 153
		AZERBAIJAN (USSR)	ca 1990	(source unknown; originally from India) <i>Anopheles sacharovi</i> Favre and <i>Culex theileri</i> Theobald first reported as hosts. These nematodes could be moved to new water bodies by moving parasitized hosts. Long term establishment unknown.	Native	2, 153

PEST ORDER: FAMILY Target pest species	Biological control agent; (Order: Family)	Release country or region	Year of release	(Source of biological control agent) Results from introduction	Pest origin	References
DIPTERA: CULICIDAE (continued) [listed in order of country of release]						
<i>Anopheles gambiae</i> Giles	<i>Romanomermis iyengari</i> Welch; (Mermithida: Mermithidae)	BENIN (in west Africa)	2011	(source unknown; originally from India) Releasing monthly suppressed <i>A. gambiae</i> . Longer term establishment not reported.	Native	1
<i>Aedes</i> spp. and <i>Ochlerotatus</i> spp.; 10 species total	<i>Romanomermis culicivorax</i> Ross & Smith [= <i>Reesimermis nielsenii</i> Tsai & Grundmann]; (Mermithida: Mermithidae)	CANADA: Manitoba	1974-76	(ex Louisiana USA) Released in snow melt pools in Winnipeg, Manitoba. 1974 release: no infection. 1975-76 releases: meager parasitism after one winter and continued persistence questionable.	Native	56, 57, 148
Anopheline spp.; and Culicine spp.	<i>Romanomermis iyengari</i> Welch; (Mermithida: Mermithidae)	CUBA	1991	(source unknown; originally from India) High levels of parasitism of <i>A. albimanus</i> Wiedemann, <i>C. nigripalpus</i> Theobald, <i>C.</i> <i>quinquefasciatus</i> Say, <i>Uranotaenia sapphirina</i> (Osten Sacken); and reduced host populations. At some sites <i>R. iyengari</i> was established for up to 5 months.	Native	153, 165
<i>Anopheles nyssorhynchus albimanus</i> Wiedemann	<i>Romanomermis culicivorax</i> Ross & Smith [= <i>Reesimermis nielsenii</i> Tsai & Grundmann]; (Mermithida: Mermithidae)	COLOMBIA	1983	(ex Louisiana USA) Released in El Valle. Established and cycled over 27 months, effectively reduced host population with coincident reduction in malaria among school children.	Native	164
<i>Anopheles nyssorhynchus albimanus</i> Weidemann and <i>A. punctipennis</i> (Say)	<i>Romanomermis culicivorax</i> Ross & Smith [= <i>Reesimermis nielsenii</i> Tsai & Grundmann]; (Mermithida: Mermithidae)	EL SALVADOR	1977	(ex Louisiana USA) Released in Lake Apasteque. Releases through year yielded 46-96% parasitism; up to 17x reduction in host populations. Recycling not reported, questionable.	Native	149, 164
<i>Anopheles dthali</i> Patton, <i>A. superpictus</i> Grassi, <i>A. sergentii</i> (Theobald), <i>A.</i> <i>turkhudi</i> Liston, and <i>A.</i> <i>culicifacies</i> Giles	<i>Romanomermis culicivorax</i> Ross & Smith [= <i>Reesimermis nielsenii</i> Tsai & Grundmann]; (Mermithida: Mermithidae)	IRAN	1984-85	(ex Louisiana USA) Established, 56-61% parasitism immediately post-release but only minor reductions in host populations. 8% parasitism at 1 of 13 sites 1 year after release. Effective long term control unlikely.	Native	204

PEST ORDER: FAMILY Target pest species	Biological control agent; (Order: Family)	Release country or region	Year of release	(Source of biological control agent) Results from introduction	Pest origin	References
DIPTERA: CULICIDAE (continued) [listed in order of country of release]						
<i>Anopheles pseudopunctipennis</i> Theobald	<i>Romanomermis iyengari</i> Welch; (Mermithida: Mermithidae)	MEXICO: Oaxaca	1996, 1999	(source unknown; originally from India) Released in Pochutla. In 1996, 85-100% parasitism, and after 2 months recovered infected mosquitos at 9 of 44 release sites. In 1999 released at 4 large breeding areas: parasitism 46-100%, mosquito populations decreased, and at 2 of the sites, nematodes recycled and persisted for 5 months.	Native	123, 146, 153
<i>Culex pipiens quinquefasciatus</i> Say and <i>Aedes aegypti</i> (L.)	<i>Octomyomermis muspratti</i> Obiamiwe & Macdonald; (Mermithida: Mermithidae)	NAURU (in Micronesia)	1967	(ex Zambia) After release, parasitism found in several tree holes but long term establishment not reported.	Introduced	107, 154
Anopheline spp. and Culicine spp.	<i>Romanomermis iyengari</i> Welch; (Mermithida: Mermithidae)	TAJIKISTAN (USSR)	ca 1990	(source unknown; originally from India) Mean infection was 46% with similar results in running and stagnant water. Infection of culicines was less than anophelines (<i>Anopheles superpictus</i> Grassi, <i>A. pulcherrimus</i> Theobald, <i>A. hyrcanus</i> group). Long term establishment unknown.	Native	153, 191
	<i>Romanomermis culicivorax</i> Ross & Smith [= <i>Reesimermis nielsenii</i> Tsai & Grundmann]; (Mermithida: Mermithidae)	TAJIKISTAN (USSR)	ca 1990	(source unknown) Mean infection was 46% with similar results in running and stagnant water. Infection of culicines was less than anophelines (<i>Anopheles superpictus</i> Grassi, <i>A. pulcherrimus</i> Theobald, <i>A. hyrcanus</i> group). Long term establishment unknown.	Native	153, 191

PEST ORDER: FAMILY Target pest species	Biological control agent; (Order: Family)	Release country or region	Year of release	(Source of biological control agent) Results from introduction	Pest origin	References
DIPTERA: CULICIDAE (continued) [listed in order of country of release]						
<i>Culex pipiens quinquefasciatus</i> Say	<i>Romanomermis culicivorax</i> Ross & Smith [= <i>Reesimermis nielsenii</i> Tsai & Grundmann]; (Mermithida: Mermithidae)	TAIWAN	1971-72	(ex Louisiana USA) Released in Taipei. Infection rates low after release and no indication of establishment.	Native	129
			1974	(ex Louisiana USA) Released in Taipei. Recycling occurred through 196 days after release but continued persistence not confirmed.	Native	31
		THAILAND	1972	(ex Louisiana USA) Large releases in ditches and drains in Bangkok, infection 0-27%, no recycling.	Native	30, 148
<i>Aedes polynesiensis</i> Marks and <i>Ae. aegypti</i> (L.)	<i>Romanomermis culicivorax</i> Ross & Smith [= <i>Reesimermis nielsenii</i> Tsai & Grundmann]; (Mermithida: Mermithidae)	TOKELAU (in the Pacific)	1978	(ex Louisiana USA) Released on Fakatao Atoll in tree holes and man-made containers. Established in 35 of 41 sites with 14-22% infection. Persisted at least 3 years.	Native & Introduced	108
<i>Anopheles freeborni</i> Aitken and <i>Culex tarsalis</i> Coquillett	<i>Romanomermis culicivorax</i> Ross & Smith [= <i>Reesimermis nielsenii</i> Tsai & Grundmann]; (Mermithida: Mermithidae)	USA: California	1975-76	(ex Louisiana USA) Released in rice fields. Continuous partial control through rice growing season with mean weekly infection for both species > 60%. Survived chemicals, drying, harvest, winter, and cultivation, and parasitized hosts next summer.	Native	148
<i>Anopheles punctipennis</i> (Say), <i>A. crucians</i> Weidemann, <i>Aedes vexans</i> (Meig.), <i>Culex restuans</i> Theobald, and <i>C. pipiens</i> L.	<i>Romanomermis culicivorax</i> Ross & Smith [= <i>Reesimermis nielsenii</i> Tsai & Grundmann]; (Mermithida: Mermithidae)	USA: Maryland	1975	(ex Louisiana USA) Established, 50-100% host mortality even 2 years after release.	Native	136

PEST ORDER: FAMILY Target pest species	Biological control agent; (Order: Family)	Release country or region	Year of release	(Source of biological control agent) Results from introduction	Pest origin	References
DIPTERA: CULICIDAE (continued) [listed in order of country of release]						
Anopheline spp. and Culicine spp.	<i>Romanomermis iyengari</i> Welch; (Mermithida: Mermithidae)	UZBEKISTAN (USSR)	ca 1990	(source unknown; originally from India) <i>Anopheles martinius</i> Schingarev, <i>A. hyrcanus</i> group, <i>Culex modestus</i> Ficalbi were parasitized after releases. <i>Aedes caspius</i> (Pallas) was not. Infection from 9-67% and only effective in water bodies with low salt content.	Native	153, 158
LEPIDOPTERA: EREBIDAE						
<i>Lymantria dispar</i> (L.); Gypsy moth	<i>Hexamermis</i> sp. (Mermithida: Mermithidae)	USA: New Jersey	1974	(ex Austria) Not established.	Introduced	36
		USA: Pennsylvania	1976	(ex Hokkaido, Japan) Not established.	Introduced	36
HYMENOPTERA: SIRICIDAE						
<i>Sirex noctilio</i> F.; European woodwasp, <i>Sirex</i> wasp	<i>Deladenus siricidicola</i> Bedding [= <i>Beddingia</i> <i>siricidicola</i> (Bedding)]; (Rhabditida: Neotylenchidae)	NEW ZEALAND: South Island	1967-74	(ex North Island, New Zealand) Released strain that sterilizes female wasps, infesting eggs before oviposition. Within first year, 29-76% infection reported, and by 1970, natural spread of ca. 50 km. Releases continued at least through 1974. Lack of establishment at some sites linked with low density host populations.	Introduced	215
		AUSTRALIA: Tasmania	1970	(ex Hungary) Established, reached high levels of parasitism rapidly. In one forest, six years after release of 50 parasitized females, trees were no longer being killed by woodwasps. Spread to nearby forests and also released in other areas. Considered the key biological agent controlling <i>Sirex</i> .	Introduced	12, 76

PEST ORDER: FAMILY Target pest species	Biological control agent; (Order: Family)	Release country or region	Year of release	(Source of biological control agent) Results from introduction	Pest origin	References
HYMENOPTERA: SIRICIDAE (continued)						
<i>Sirex noctilio</i> F. (continued)	<i>Deladenus siricidicola</i> Bedding (continued)	AUSTRALIA: Victoria	1971	(<i>ex Tasmania and other locations</i>) Established, dispersed by woodwasps in local forests and by humans between forests. Use of this nematode became a cornerstone in the National Sirex Control strategy. Released over many years in many areas; 147,000 <i>radiata</i> pines inoculated in the Green Triangle in 1987 alone. With over 20 years of <i>in vitro</i> production, strain lost virulence resulting in replacement of strain used for releases.	Introduced	14, 76
		URUGUAY	1987	(<i>ex New Zealand</i>) Established, yielding 18% parasitism.	Introduced	21, 157, 166
		BRAZIL	1989-90, 1994	(<i>ex Australia</i>) Principally released in 3 southern provinces. After loss of infectivity, new strain (Kamona from Tasmania) introduced in 1994, yielding 50-80% parasitism. Established, >70% parasitism reported in 2012, in addition to very low density <i>S. noctilio</i> populations.	Introduced	14, 84, 85, 86
		SOUTH AFRICA: Western Cape	1995-96	(<i>ex Australia</i>) Released Kamona strain. Established, with 23% parasitism reported in 1996. In 1998, along with cultural control, credited with containing the spread of the pest in the Western Cape region. Later studies documented more variable levels of parasitism, but still established in 2015.	Introduced	81, 83, 189, 190
		SOUTH AFRICA: Eastern Cape and Kwa-Zulu Natal	2004-06	(<i>ex Australia</i>) Released Kamona strain. Yielded low parasitism of 5-10%. Poor results most closely associated with low moisture levels within pines. In 2015, considered established.	Introduced	81, 82, 83

PEST ORDER: FAMILY Target pest species	Biological control agent; (Order: Family)	Release country or region	Year of release	(Source of biological control agent) Results from introduction	Pest origin	References
HYMENOPTERA: SIRICIDAE (continued)						
<i>Sirex noctilio</i> F. (continued)	<i>Deladenus siricidicola</i> Bedding (continued)	SOUTH AFRICA: Mpumulanga and Limpopo	2010+, 2012+	(<i>ex South Africa, from earlier Kamona release sites</i>) Releases begun 2010 in Mpumulanga; 2012 in Limpopo. Annual inoculations in areas of low parasitism, but in 2015 considered established.	Introduced	81
		ARGENTINA: Misiones and Corrientes Provinces	1996, 1998- 99, +	(<i>ex Brazil</i>) Brazilian Encruzilhada do Sul strain, originally from Australia. Parasitism 0-4.8% in 1999. More releases annually, especially 2003-2009. As of 2015, average of 25% parasitism in Corrientes where greater <i>Sirex</i> attacks occur.	Introduced	11, 49, 83
		ARGENTINA: Patagonia	1999, 2001-06	(<i>ex Brazil and New Zealand</i>) Established, 50-60% parasitism reported at release site in 2000, nearly 100% parasitism in 2007, although overall parasitism highly variable. Inoculations 2001-2006 did not slow the spread of <i>Sirex</i> .	Introduced	35, 83, 98, 99, 100
		CHILE	2006-09	(<i>ex Brazil and New Zealand</i>) Released Encruzilhada do Sul strain from Brazil; Tangoio strain from New Zealand. Established, and parasitism levels increased from 2007-09.	Introduced	18

TABLE G: Accidental Introductions of Pathogens and Nematodes, by Pest Species

PEST ORDER: FAMILY Pest species	Pathogen/Nematode; (Group)	Country or region of first observation	Year found	(<i>Likely origin</i>) Results from introduction	Pest origin	References
LEPIDOPTERA: ZYGAENIDAE						
<i>Harrisina brillians</i> Barnes & McDunnough; Western grape skeletonizer	<i>Harrisina brillians</i> granulovirus (HbGV) ; (Baculoviridae: <i>Betabaculovirus</i>)	USA: California	Early 1950s	(<i>probably from Mexico and/or Arizona USA</i>) Found in San Diego Co., California, probably inadvertently introduced with parasitoids. Infections observed in field and virus continually wiped out colonies for rearing parasitoids.	Introduced	182, 183
LEPIDOPTERA: CRAMBIDAE						
<i>Ostrinia nubilalis</i> (Hübner); European corn borer	<i>Nosema pyrausta</i> (Paillot) [= <i>Perezia pyraustae</i> Paillot; = <i>Glugea pyraustae</i> (Paillot)]; (Microsporidia: Clade 4, Branch A)	USA: New Jersey	1949	(<i>probably from Europe</i>) Possibly introduced with parasitoids. First found in New Jersey but subsequently found throughout the host distribution in the USA. Occurring commonly, epizootics develop with high host density and widespread spatial distribution of hosts.	Introduced	26, 73, 180
LEPIDOPTERA: EREBIDAE						
<i>Lymantria dispar</i> (L.); Gypsy moth	<i>Lymantria dispar multiple</i> nucleopolyhedrovirus (LdMNPV); (Baculoviridae: <i>Alphabaculovirus</i>)	USA: northeast	1907	(<i>probably from Europe</i>) Thought to have been introduced after 1900 with parasitoids released in Massachusetts for classical biological control or with plant material and spread through the host population. Until <i>E. maimaiga</i> became established, caused epizootics in high density, tree-defoliating populations of <i>L. dispar</i> , resulting in spectacular population crashes. Spreads naturally after the host population spreads into new areas.	Introduced	59, 65, 72

PEST ORDER: FAMILY Pest species	Pathogen/Nematode; (Group)	Country or region of first observation	Year found	(<i>Likely origin</i>) Results from introduction	Pest origin	References
LEPIDOPTERA: EREBIDAE (continued)						
<i>Lymantria dispar</i> (L.) (continued)	<i>Entomophaga maimaiga</i> Humber, Shimazu & Soper; (Entomophthorales: Entomophthoraceae)	USA: northeast	1989	(<i>from Japan; apparently sometime after 1971; not same strain as 1985-86 releases; very unlikely from 1910-11 releases</i>) First found in 1989 in 7 northeastern states (Connecticut, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Vermont). By 1990 in 3 more states and Ontario, Canada; by 1992 across contiguous host distribution in northeast. Spread naturally and through releases. By 2005 established in: Delaware, Maine, Maryland, Michigan, North Carolina, Ohio, Rhode Island, Virginia, Wisconsin, West Virginia, the first 7 states and Ontario. Host populations remain low the majority of years and sites, although localized increases occur infrequently especially in some regions. Spreads naturally after the host population spreads into new areas.	Introduced	48, 65, 67, 69, 72, 137
		GEORGIA (in Eurasia)	2005	(<i>source unknown; originally from Japan</i>) High levels of infection found in an outbreak host population. Slight molecular differences with US strains so spread from Bulgaria (where US strains introduced) questionable.	Native	94
HYMENOPTERA: SIRICIDAE						
<i>Sirex noctilio</i> F.; European woodwasp, Sirex wasp	<i>Deladenus siricidicola</i> Bedding [= <i>Beddingia</i> <i>siricidicola</i> (Bedding)]; (Nematoda: Rhabditida: Neotylenchidae)	NEW ZEALAND: North Island	1962	(<i>source unknown; Europe?</i>) Thought to have arrived with host. Attributed with being the most important agent controlling host on the North Island, where the <i>Deladenus</i> strain that sterilizes the female (infesting the eggs before oviposition) was first found in introduced <i>Sirex</i> populations.	Introduced	13, 213, 215

PEST ORDER: FAMILY Pest species	Pathogen/Nematode; (Group)	Country or region of first observation	Year found	(<i>Likely origin</i>) Results from introduction	Pest origin	References
HYMENOPTERA: SIRICIDAE (continued)						
<i>Sirex noctilio</i> F. (continued)	<i>Deladenus siricidicola</i> Bedding (continued)	NEW ZEALAND: North Island	1971	(<i>source unknown</i>) In the northern end of the North Island a non-sterilizing strain was found in 1971 and 1973; assumed to be a separate accidental introduction from the sterilizing strain.	Introduced	214
		CANADA and USA	2007-11	(<i>source unknown; Europe?</i>) Non-sterilizing strain found in <i>S. noctilio</i> in Ontario 2007-08 and 2011 in New York and Pennsylvania. Believed brought in by <i>S. noctilio</i> (first found in 2004 in NY; 2005 in Ontario). Nematodes in the reproductive tract remain outside the eggs of the host; infected adult females tend to be smaller and produce fewer eggs. A lower proportion of adult males was infected. In New York and Pennsylvania the non-sterilizing strain was at all 7 sites that had <i>S. noctilio</i> , but not in all trees or host adults.	Introduced	105, 203
HYMENOPTERA: DIPRIONIDAE						
<i>Gilpinia hercyniae</i> (Hartig) [= <i>Diprion hercyniae</i> Hartig]; European spruce sawfly	<i>Gilpinia hercyniae nucleopolyhedrovirus</i> (GhNPV); (Baculoviridae: <i>Gammabaculovirus</i>)	CANADA and USA	1936	(<i>probably from Europe</i>) Believed introduced with parasitoids. Virus first found in New Brunswick and then Maine, Vermont, and New Hampshire, after which it spread from south to north and first found in Quebec in 1940. Also transferred to sites in Quebec and Ontario but some transfers were unsuccessful and virus spread on its own. By 1942, virus was distributed throughout most of the infested areas and was credited as cause of rapid decline in pest outbreak after 1942. Virus plus parasitoids appear to have permanently solved problems due to this pest in eastern North America.	Introduced	7, 25, 40, 41, 119

PEST ORDER: FAMILY Pest species	Pathogen/Nematode; (Group)	Country or region of first observation	Year found	(<i>Likely origin</i>) Results from introduction	Pest origin	References
HYMENOPTERA: DIPRIONIDAE (continued)						
<i>Gilpinia hercyniae</i> (Hartig) (continued)	<i>Gilpinia hercyniae</i> <i>nucleopolyhedrovirus</i> (GhNPV); (continued)	UK: WALES	1970/71	(<i>probably from Europe</i>) Spread from small epicenter and controlled pest outbreak by 1974.	Introduced	41, 50
HYMENOPTERA: FORMICIDAE						
<i>Solenopsis invicta</i> Buren; Red imported fire ant	<i>Thelohania solenopsae</i> Knell, Allen & Hazard; (Microsporidia: Clade 3)	USA: Florida	1996	(<i>from South America</i>) Found in Florida. Infects mostly polygynous colonies. Chronic debilitation of infected queens yields smaller colony sizes and possibly prolonged death of colonies.	Introduced	144, 194

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APPENDIX I: Taxonomic List of the Pathogens and Nematodes¹

Virus, Group I (dsDNA)

Family Baculoviridae

Genus *Alphabaculovirus*

Anticarsia gemmatalis multiple nucleopolyhedrovirus (AgMNPV)

Lymantria dispar multiple nucleopolyhedrovirus (LdMNPV)

Lymantria monacha nucleopolyhedrovirus (LmNPV)

Pseudoplusia includens single nucleopolyhedrovirus (PsinSNPV)

Trichoplusia ni nucleopolyhedrovirus (TnNPV)

Genus *Betabaculovirus*

Agrotis segetum granulovirus (AsGV)

Harrisina brillians granulovirus (HbGV)

Genus *Gammabaculovirus*

Gilpinia hercyniae nucleopolyhedrovirus (GhNPV)

Neodiprion sertifer nucleopolyhedrovirus (NeseNPV)

Family Nudiviridae

Genus *Alphanudivirus*

Oryctes rhinoceros nudivirus (OrNV)

Domain Bacteria

Phylum Firmicutes

Class Bacilli

Order Bacillales

Family Paenibacillaceae

Paenibacillus popilliae

Domain Eukarya

Kingdom Fungi

Phylum Blastocladiomycota

Class Blastocladiomycetes

Order Blastocladales

Family Coelomomycetaceae

Coelomomyces stegomyiae

Phylum Entomophthoromycota

Class Entomophthoromycetes

Order Entomophthorales

Family Entomophthoraceae

Entomophaga grylli

Entomophaga maimaiga

Pandora neoaphidis

Zoophthora radicans

Class Neozygitomycetes

Order Neozygitales

Family Neozygitaceae

Neozygites fresenii

Neozygites parvispora

Neozygites tanajoae

Phylum Ascomycota

Class Dothideomycetes

Order Myriangiiales

Family Myriangiaceae

Myriangium duriaei

Order Pleosporales

Family Tubeufiaceae

Podonectria coccophila

Class Sordariomycetes

Order Hypocreales²

Family Clavicipitaceae

Aschersonia aleyrodis

Aschersonia goldiana

Aschersonia spp.

Metarhizium anisopliae

Family Cordycipitaceae

Beauveria bassiana

Beauveria brongniartii

Lecanicillium lecanii

Family Nectriaceae

Fusarium coccophilum

Fusarium juruanum

Family Ophiocordycipitaceae

Hirsutella thompsonii var. *synnematos*

Hirsutella thompsonii var. *vinacea*

Domain Eukarya (continued)**Phylum Microsporidia**

Clade 2

Paranosema locustae

Clade 3

Thelohania solenopsae

Clade 4

Branch A³*Nosema lymantriae**Nosema portugal**Nosema pyrausta**Vairimorpha disparis*Branch B³*Endoreticulatus schubergi*

Clade 5

*Vavraia culicis***Supergroup SAR⁴** (includes stramenopiles, alveolates and *Rhizaria*)

Phylum Heterokontophyta (Heterokonta; Stramenopiles)

Class Peronosporomycetes (Oomycota)

Order Lagenidiales**Family Lagenidiaceae***Lagenidium giganteum***Kingdom Animalia****Phylum Nematoda⁵**

Class Enoplea

Order Mermithida

Family Mermithidae*Hexameris* sp.*Octomyomermis muspratti**Romanomermis culicivorax**Romanomermis iyengari*

Class Chromadorea

Order Rhabditida

Family Rhabditidae*Rhabditis* sp.*Rhabditis* sp. nr. *maupasi***Family Heterorhabditidae***Heterorhabditis bacteriophora***Family Steinernematidae***Steinernema scapterisci***Family Neotylenchidae***Deladenus siricidicola*

¹ Higher order classification of numerous of these groups has recently been changed or is in a state of flux and we have received guidance from experts working on these different groups. Classification for viruses is in keeping with King et al. (2012), and higher order classification of Microsporidia is presently based on clades (Vossbrinck et al. 2014).

² In the Hypocreales, the anamorph names are listed here; generic names are in flux and some may be replaced in the future with names of teleomorphic genera.

³ Within Clade 4 of Microsporidia the designation of letters for branches is informal and only provided to show differences.

⁴ The placement of SAR and classification within the group is in a state of flux.

⁵ Nematode higher classification based on De Ley and Blaxter (2004).

APPENDIX II: Taxonomic List of the Insect and Mite Pests

Kingdom Animalia

Phylum Arthropoda

Class Insecta

Order Orthoptera

- Family Gryllotalpidae
 - Scapteriscus abbreviatus*
 - Scapteriscus borelli*
 - Scapteriscus didactylus*
 - Scapteriscus vicinus*
- Family Acrididae
 - Camnula pellucida*
 - Dichroplus elongatus*
 - Dichroplus maculipennis*
 - Dichroplus pratensis*
 - Melanoplus bivittatus*
 - Melanoplus sanguinipes*
 - Phaulacridium vittatum*
 - Scotussa lemniscata*

Order Hemiptera

- Family Cercopidae
 - Aeneolamia flavilatera*
- Family Cicadellidae
 - Empoasca fabae*
- Family Aphididae
 - Aphis gossypii*
 - Diuraphis noxia*
 - Macrosiphum solanifolii*
 - Metopolophium dirhodum*
 - Therioaphis maculata*
- Family Aleyrodidae
 - Aleurodicus cocois*
 - Aleurothrixus floccosus*
 - Dialeurodes citri*
 - Dialeurodes* sp.
 - Singhiella citrifolii*

Family Coccidae

- Ceroplastes rubens*
- Coccus viridis*
- Eucalymnatus tessellatus*

Family Diaspididae

- Aonidiella aurantii*
- Aspidiotus destructor*
- Lepidosaphes beckii*
- Quadrispidiotus perniciosus*

Order Thysanoptera

Family Thripidae

- Thrips tabaci*

Order Coleoptera

Family Scarabaeidae

- Adoretus tenuimaculatus*
- Alissonotum impressicolle*
- Anoplognathus* sp.
- Cochliotis melolonthoides*
- Dermolepida albohirtum*
- Lepidiota pruinosa*
- Lepidiota* sp.
- Leucopholis irrorata*
- Oryctes monoceros*
- Oryctes rhinoceros*
- Papuana huebneri*
- Popillia japonica*
- Phyllophaga smithi*
- Scapanes australis*
- Schizonycha* sp.

Family Curculionidae

- Otiorhyncus arcticus*
- Otiorhyncus nodosus*
- Rhabdoscelus obscurus*
- Sitona discoideus*

Order Diptera

Family Culicidae

- Aedes aegypti*
- Aedes caspius*
- Aedes polynesiensis*
- Aedes* spp.
- Aedes vexans*
- Anopheles albimanus*
- Anopheles crucians*
- Anopheles culicifacies*
- Anopheles dthali*
- Anopheles freeborni*
- Anopheles gambiae*
- Anopheles hyrcanus* group
- Anopheles martinus*
- Anopheles nyssorhynchus albimanus*
- Anopheles pseudopunctipennis*
- Anopheles pulcherrimus*
- Anopheles punctipennis*
- Anopheles sacharovi*
- Anopheles sergentii*
- Anopheles superpictus*
- Anopheles turkhudi*
- Culex modestus*
- Culex nigripalpus*
- Culex pipiens*
- Culex pipiens quinquefasciatus*
- Culex quinquefasciatus*
- Culex restuans*
- Culex tarsalis*
- Culex theileri*
- Ochlerotatus* spp.
- Uranotaenia sapphirina*
- Uranotaenia unguiculata*

Kingdom Animalia (continued)**Phylum Arthropoda** (continued)**Class Insecta** (continued)**Order Lepidoptera**

Family Zygaenidae

Harrisina brillians

Family Crambidae

Ostrinia nubilalis

Family Erebidae

*Anticarsia gemmatalis**Lymantria dispar**Lymantria monacha*

Family Noctuidae

*Agrotis segetum**Pseudoplusia includens**Trichoplusia ni***Order Hymenoptera**

Family Siricidae

Sirex noctilio

Family Diprionidae

*Gilpinia hercyniae**Neodiprion sertifer*

Family Formicidae

*Solenopsis invicta***Class Arachnida: Subclass Acari****Order Prostigmata**

Family Eriophyidae

*Eriophyes sheldoni**Phyllocoptura oleivora*

Family Tetranychidae

Mononychellus tanajoa

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Addendum to TABLE C: Exotic Fungi Released, by Target Pest (Added In press 2016)

PEST ORDER: FAMILY Target pest species	Biological control agent; (Order: Family)	Release country or region	Year of release	(Source of biological control agent) Results from introduction	Pest origin	References
COLEOPTERA: SCARABAEIDAE						
<i>Hoplochelus marginalis</i> (Fairmaire); Sugarcane white grub	<i>Beauveria hoplocheli</i> I. Robène-Soustrade & S. Nibouche [previously reported as <i>B. brongniartii</i>]; (Hypocreales: Cordycipitaceae)	REUNION ISLAND (in the Indian Ocean)	1987	(ex Madagascar) Successful control was achieved where released but since use was in sugarcane crops that are not permanent, this fungus is mass produced and used for augmentation.	Introduced	1A, 1B, 1C
	<i>Metarhizium anisopliae</i> (Metschnikoff) Sorokin; (Hypocreales: Clavicipitaceae)	REUNION ISLAND (in the Indian Ocean)	1987	(ex Australia) No control although persisting at low levels from year to year.	Introduced	1B, 1C

1A. Robène-Soustrade, I., E. Jouen, D. Pastou, M. Payet-Hoarau, T. Goble, D. Linderme, P. Lefeuvre, C. Calmès, B. Reynaud, S. Nibouche and L. Costet. 2015. Description and phylogenetic placement of *Beauveria hoplocheli* sp. nov. used in the biological control of the sugarcane white grub, *Hoplochelus marginalis*, on Reunion Island. *Mycologia* 107: 1221-1232.

1B. Vercambre, B., O. Goebel, G. Riba, G. Morel, P. Robert and M. Guillon. 1991. Programme de lutte biologique contre *Hoplochelus marginalis* (Coleoptera: Melolonthinae), nouveau ravageur des cultures à l'île de la Réunion. In: (C. Pavis and A. Kermarrec, Eds.) Les Colloques n 58. Rencontres Caraïbes en Lutte Biologique; 5-7 Nov 1990. Guadeloupe: INRA, pp. 371-378.

1C. Vercambre, B., O. Goebel, G. Riba, M. Marchal, C. Neuvéglise and P. Ferron. 1994. Success in biological control of a soil pest, *Hoplochelus marginalis*, in Reunion Island: choice of a suitable fungus. 6th International Colloquium on Invertebrate Pathology and Microbial Control; 28 Aug.-2 Sept. 1994; Montpellier, France: Soc. Invertebrate Pathology, pp. 283-288.