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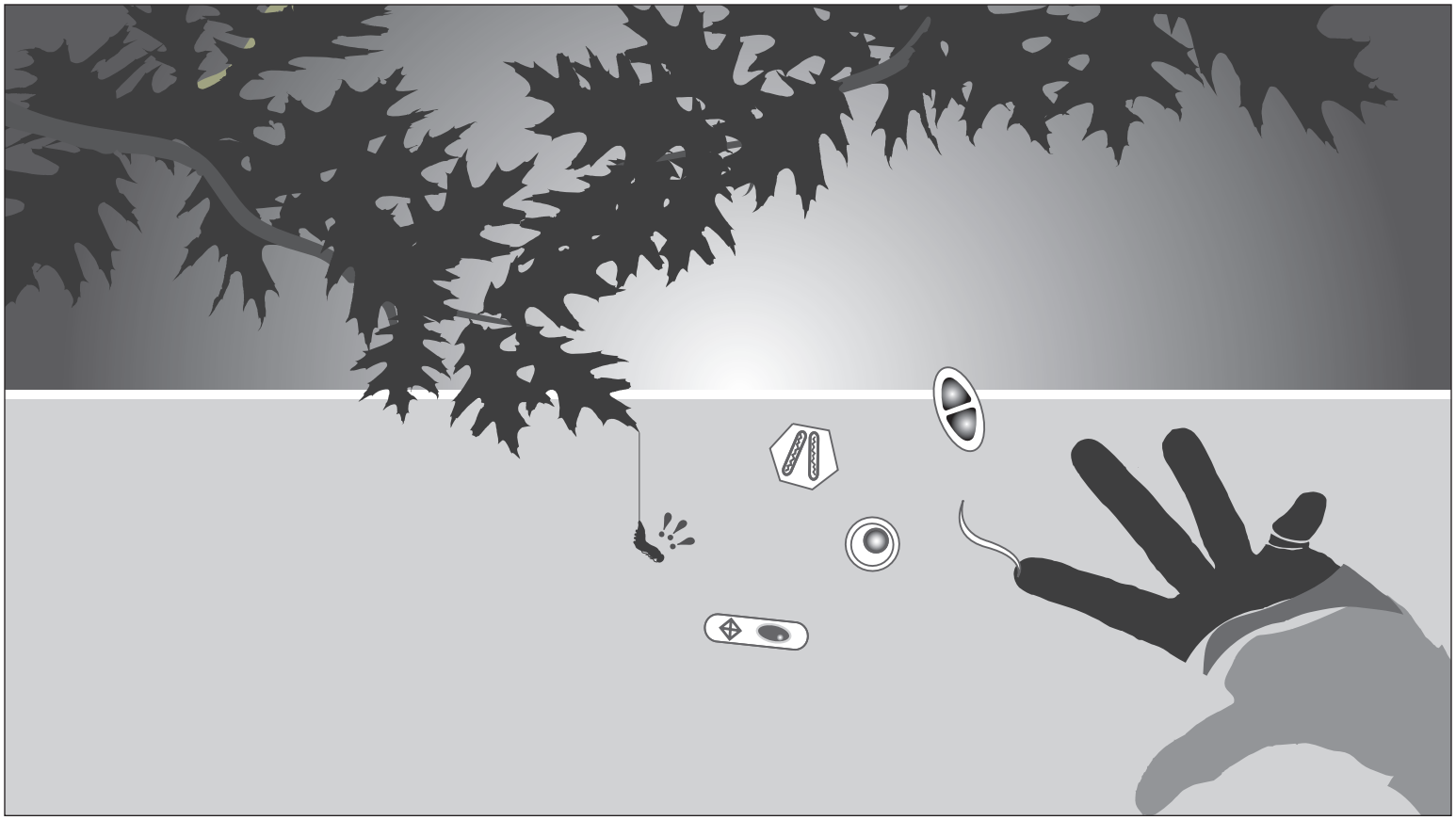
Classical Biological Control of Insects and Mites:

A Worldwide Catalogue of Pathogen and Nematode Introductions



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Forest Health Technology Enterprise Team

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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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CONTENTS

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: *Genus*)	Release country or region	Year of release	*(Source of biological control agent)* Results from introduction	Pest origin	References
COLEOPTERA: SCARABAEIDAE						
Oryctes monoceros (Olivier); African rhinoceros beetle or Coconut beetle	***Oryctes rhinoceros nudivirus* (OrNV)** [= *Rhabdionvirus oryctes* (Huger); = *Baculovirus oryctes* Huger]; (Nudiviridae: *Alphanudivirus*)	**SEYCHELLES** (in the Indian Ocean)	1973	*(ex Samoa)* 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	*(ex Praslin Island group, Seychelles)* Established on Mahé and Ste. Anne with 20-50% infection and 30% reduction in beetle population.	Native	112, 113
		TANZANIA	1983-87	*(ex Philippines and Samoa)* 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
Oryctes rhinoceros (L.); Asiatic or Coconut rhinoceros beetle	***Oryctes rhinoceros nudivirus* (OrNV)** [= *Rhabdionvirus oryctes* (Huger); = *Baculovirus oryctes* Huger]; (Nudiviridae: *Alphanudivirus*)	**SAMOA** (Western Samoa)	1967	*(ex Malaysia)* 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	*(ex Malaysia)* 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: *Genus*)	Release country or region	Year of release	*(Source of biological control agent)* Results from introduction	Pest origin	References
COLEOPTERA: SCARABAEIDAE (continued)						
Oryctes rhinoceros (L.) (continued)	***Oryctes rhinoceros nudivirus*** **(OrNV)** (continued)	**FIJI**	1970-74	*(ex Samoa)* 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	*(ex Samoa)* Established on Babeldaob Island, controlling beetles.	Introduced	167, 184
			1983	*(ex Samoa)* 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	*(ex Samoa)* 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	*(ex Samoa)* 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	*(ex Samoa)* Established, beetle populations declined sharply from 1970. At least through 1976-77, damage reduced by 60-95%.	Introduced	17, 134
		AMERICAN SAMOA	1972	*(ex Samoa)* 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: *Genus*)	Release country or region	Year of release	*(Source of biological control agent)* Results from introduction	Pest origin	References
COLEOPTERA: SCARABAEIDAE (continued)						
Oryctes rhinoceros (L.) (continued)	***Oryctes rhinoceros nudivirus*** **(OrNV)** (continued)	**JAVA** (Indonesia)	1976-80	*(ex Sumatra, Indonesia)* 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	*(ex Samoa)* Released on 3 islands. Established at nearly all sites, spread at 1 km/month.	Introduced	62
		INDIA: Minicoy Island	1983-84	*(ex Kerala, India)* 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	*(ex Philippines, Tanzania, and Malaysia)* 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	*(ex Kerala, India)* 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	*(ex Kerala, India)* Released on Andrott (Androth) Island. Successful introduction. In 1990, coconut palm crop damage measurably less and virus incidence > 60%.	Native	61

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)						
Oryctes rhinoceros (L.) (continued)	***Oryctes rhinoceros nudivirus* (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
Scapanes australis (Boisduval); Melanesian rhinoceros beetle	***Oryctes rhinoceros nudivirus (OrNV)*** [= *Rhabdionvirus oryctes* (Huger); = *Baculovirus oryctes* Huger]; (Nudiviridae: *Alphanudivirus*)	**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						
Harrisina brillians Barnes & McDunnough; Western grapeleaf skeletonizer	***Harrisina brillians granulovirus* (HbGV)**; (Baculoviridae: *Betabaculovirus*)	**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						
Anticarsia gemmatalis Hübner; Velvetbean caterpillar	***Anticarsia gemmatalis multiple nuclepolyhedrovirus* (AgMNPV)**; (Baculoviridae: *Alphabaculovirus*)	**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
Lymantria dispar (L.); Gypsy moth	***Lymantria dispar multiple nucleopolyhedrovirus* (LdMNPV)**; (Baculoviridae: *Alphabaculovirus*)	**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: *Genus*)	Release country or region	Year of release	*(Source of biological control agent)* Results from introduction	Pest origin	References
LEPIDOPTERA: EREBIDAE (continued)						
Lymantria monacha L.; Nun moth	***Lymantria monacha nucleopolyhedrovirus* (LmNPV)**; (Baculoviridae: *Alphabaculovirus*)	**DENMARK**	1973-74	*(ex Sweden and West Germany)* 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						
Trichoplusia ni (Hübner); Cabbage looper	***Trichoplusia ni nucleopolyhedrovirus* (TnNPV)**; (Baculoviridae: *Alphabaculovirus*)	**COLOMBIA**	1970	*(ex California USA)* Persisted after release, controlling subsequent pest generations.	Introduced	19, 39
Pseudoplusia includens (Walker); Soybean looper	***Pseudoplusia includens single nucleopolyhedrovirus* (PsinSNPV)**; (Baculoviridae: *Alphabaculovirus*)	**USA: Louisiana**	1975-77	*(ex Guatemala)* Released in soybean fields. Established; 38-63% infection 12-15 years after introduction.	Native	55
Agrotis segetum (Denis & Schiffermüller); Turnip moth	***Agrotis segetum granulovirus* (AsGV)**; (Baculoviridae: *Betabaculovirus*)	**DENMARK**	1975-80	*(ex Austria)* 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						
Gilpinia hercyniae (Hartig) [= *Diprion hercyniae* Hartig]; European spruce sawfly	***Gilpinia hercyniae nucleopolyhedrovirus* (GhNPV)**; (Baculoviridae: *Gammabaculovirus*)	**CANADA: Newfoundland**	1943-45	*(ex mainland Canada)* 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: *Genus*)	Release country or region	Year of release	*(Source of biological control agent)* Results from introduction	Pest origin	References
HYMENOPTERA: DIPRIONIDAE (continued)						
Gilpinia hercyniae (Hartig) (continued)	***Gilpinia hercyniae nucleopolyhedrovirus*** **(GhNPV)** (continued)	**CANADA: Ontario**	1950	*(ex New Brunswick, Canada)* 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
Neodiprion sertifer (Geoffrey); European pine sawfly	***Neodiprion sertifer nucleopolyhedrovirus*** **(NeseNPV)**; (Baculoviridae: *Gammabaculovirus*)	**CANADA: Ontario**	1950+	*(ex Sweden)* 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	*(ex Canada)* Established and spread (ca. 300 m from individual trees after release). Released also in 1952. Provided complete control.	Introduced	45
		USA: Illinois	1952	*(ex New Jersey USA; originally Canada)* 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	*(ex Canada)* Reported as maintaining adequate control over several years through recurring epizootics after establishment.	Introduced	168
		UK: SCOTLAND	1961	*(ex Canada)* 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						
Cochliotis melolonthoides (Gerstaecker)	***Paenibacillus popilliae*** (Dutky); (Paenibacillaceae)	**TANZANIA**	1968	*(ex USA, probably)* Strain from Japanese beetle, *Popillia japonica* Newman. Seemed to become established but this is not certain due to presence of an indigenous milky disease.	Native	63
Oryctes rhinoceros (L.); Asiatic or Coconut rhinoceros beetle	***Paenibacillus popilliae*** (Dutky); (Paenibacillaceae)	**PALAU** (in Micronesia)	1951	*(ex USA)* Strain from Japanese beetle, *Popillia japonica* Newman. Not recovered after release.	Introduced	184
		AMERICAN SAMOA	1957	*(ex USA)* Strain from Japanese beetle, *Popillia japonica* Newman. Not recovered after release.	Introduced	184
Papuana huebneri (Halmahera); Taro beetle	***Paenibacillus popilliae*** (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
Popillia japonica (Dutky); Japanese beetle	***Paenibacillus popilliae*** (Dutky); (Paenibacillaceae)	**AZORES: Terceira Island**	1990-91	*(ex USA)* Did not appear to be effective. Establishment is questionable.	Introduced	106, 122
Schizonycha sp.	***Paenibacillus popilliae*** (Dutky); (Paenibacillaceae)	**KENYA**	1956	*(ex USA)* A and B strains from Japanese beetle, *Popillia japonica* 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						
Melanoplus sanguinipes (F.); Migratory grasshopper	***Entomophaga grylli*** (Fresenius) Batko, pathotype III; (Entomophthorales: Entomophthoraceae)	**USA: Alaska**	1990	*(ex Australia)* No establishment.	Native	28, 161
Melanoplus bivittatus (Say); Two-striped grasshopper; ***M. sanguinipes*** (F.); Migratory grasshopper; ***Camnula pellucida*** Scudder; Clearwinged grasshopper; and other spp.	***Entomophaga grylli*** (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 Melanoplinae, but not *Hesperotettix viridis* (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
Phaulacridium vittatum (Sjöstedt); Wingless grasshopper	***Entomophaga grylli*** (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						
Aeneolamia flavilatera (Urich)	***Metarhizium anisopliae*** (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						
Empoasca fabae (Harris); Potato leafhopper	***Zoophthora*** (= *Erynia*) ***radicans*** (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						
Aphis gossypii Glover; Cotton aphid	***Neozygites fresenii*** (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
Diuraphis noxia Kurdjumov; Russian wheat aphid	***Zoophthora radicans*** (Brefeld) Batko; (Entomophthorales: Entomophthoraceae)	**USA: Idaho**	1992	*(ex Serbia)* To release, parasitoids *Aphelinus asychis* (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
Macrosiphum solanifolii (Ashmead); Potato aphid	Probably in ***Lecanicillium*** (= *Verticillium*) ***lecanii* species complex** [Reported as *Acrostalagmus* 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)						
Metopolophium dirhodum (Walker); Rose-grain aphid; and other cereal aphid spp.	***Pandora neoaphidis*** (Remaudière & Hennebert) Humber; (Entomophthorales: Entomophthoraceae)	**BELGIUM**	1982	*(ex Brazil)* Isolate chosen due to good *in vitro* growth. Limited transmission in field after release, probably because few conidia are produced by isolate. Limited transmission suggests poor chance of establishment.	Native	110
Therioaphis maculata (Buckton); Spotted alfalfa aphid	***Zoophthora radicans*** (Brefeld) Batko [= *Entomophthora sphaerosperma* Fresenius]; (Entomophthorales: Entomophthoraceae)	**AUSTRALIA: New South Wales**	1979	*(ex Israel)* 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						
Aleurodicus cocois (Curtis); Coconut whitefly; and ***Aleurothrixus floccosus*** (Maskell); Woolly whitefly	***Aschersonia aleyrodis*** Webber; (Hypocreales: Clavicipitaceae)	**VIRGIN ISLANDS**	Before 1920	*(source unknown)* No establishment due to high winds and drought.	Native?	195
Dialeurodes sp.; Whitefly	***Aschersonia aleyrodis*** Webber; (Hypocreales: Clavicipitaceae)	**BERMUDA**	1926	*(ex Florida USA)* Establishment and persistence not reported.	Unknown	143
Singhiella citrifolii (Morgan) [= *Dialeurodes citrifolii* Morgan]; Cloudywinged whitefly	***Aschersonia goldiana*** Saccardo & Ellis; (Hypocreales: Clavicipitaceae)	**BERMUDA**	1924	*(ex Florida USA)* 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)						
Dialeurodes citri (Ashmead); Citrus whitefly	***Aschersonia*** spp.; (Hypocreales: Clavicipitaceae)	**USSR: AZERBAIJAN and GEORGIA**	1960-64	*(ex China, Cuba, India, Japan, Trinidad, USA, and Vietnam)* 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 *A. placenta* 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 *Aschersonia* spp.), the pest was kept below the economic threshold.	Introduced	88, 117, 155, 159
Unspecified species of whitefly	**Unidentified fungus**	**USA: Hawaii**	1909	*(ex Florida USA)* One species released. Results not reported.	Unknown	104
HEMIPTERA: COCCIDAE						
Coccus viridis (Green); Green scale	**Unidentified fungus** [possibly in *Lecanicillium* (= *Verticillium*) *lecanii* species complex]; (Hypocreales: Cordycipitaceae)	**USA: Hawaii**	1928 or before	*(ex Florida USA)* Established and provided effective control.	Introduced	87, 185
Coccus viridis (Green); Green scale; ***Eucalymnatus tessellatus*** (Signoret); Tesselated scale; and ***Ceroplastes rubens*** Maskell; Red wax scale	***Lecanicillium lecanii*** (Zimmerman) Gams & Zare [= *Verticillium lecanii* (Zimmerman); = *Cephalosporium lecanii* Zimmerman]; (Hypocreales: Cordycipitaceae)	**SEYCHELLES** (in the Indian Ocean)	1911	*(ex Sri Lanka (Ceylon))* 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)						
Coccus viridis (Green); Green scale; and other **Lecaniine** scale spp.	***Lecanicillium lecanii*** (Zimmerman) Gams & Zare [= *Verticillium lecanii* (Zimmerman); = *Cephalosporium lecanii* Zimmerman]; (Hypocreales: Cordycipitaceae)	**SEYCHELLES** (in the Indian Ocean)	Before 1933	*(ex India)* Well established on lecaniine scales, especially *Coccus viridis* 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						
Aonidiella aurantii (Maskell); California red scale	***Fusarium coccophilum*** (Desmazieres) Wollenweber & Reinking [= *Fusarium episphaerea* f. *coccophila* Tul.]; teleomorph = *Nectria flammea* (Tulasne & Tulasne) Dingley; (Hypocreales: Nectriaceae)	**ARGENTINA**	1900	*(ex USA)* Established and occasionally caused up to 90% mortality in northeastern and northwestern regions.	Introduced	38
Aspidiotus destructor Signoret; Coconut scale	***Fusarium juruanum*** P. Hennings [= *Pseudomicrocera henningsii* (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)						
Lepidosaphes beckii (Newman) [= *Cornuaspis beckii* (Newman)]; Purple or Mussel scale	***Fusarium coccophilum*** (Desmazieres) Wollenweber & Reinking [= *Sphaerostilbe coccophila* Tul.]; teleomorph = *Nectria flammea* (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
	Podonectria coccicola Petch; (Pleosporales: Tubeufiaceae)	**BERMUDA**	1926	*(ex Florida USA)* Establishment and persistence not reported.	Introduced	143
	Myriangium duriaei Montagne & Berkeley [1st edition listed as *Triblidium caespitosum*]; (Myriangiales: Myriangiaceae)	**BERMUDA**	1926	*(ex Florida USA)* Released on infested citrus trees throughout the island. Found already present on *L. beckii* at one site. Establishment and persistence not reported.	Introduced	143
Quadraspidiotus perniciosus (Comstock) [= *Aspidiotus perniciosus* Comstock]; San Jose scale	***Fusarium coccophilum*** (Desmazieres) Wollenweber & Reinking [= *Sphaerostilbe coccophila* Tul.]; teleomorph = *Nectria flammea* (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: THRIPIDAE						
Thrips tabaci Lindeman; Onion thrips	***Neozygites parvispora*** (MacLeod & Carl) Remaudiére & Keller; (Neozygitales: Neozygitaceae)	**BARBADOS**	1973-76	*(ex Switzerland)* Released in onion field but no establishment.	Introduced	33
COLEOPTERA: SCARABAEIDAE						
Adoretus tenuimaculatus Waterhouse	***Metarhizium anisopliae*** (Metschnikoff) Sorokin; (Hypocreales: Clavicipitaceae)	**FIJI**	Before 1918	*(source unknown)* Some signs that this fungus acted as a check on the beetles.	Introduced	101
Alissonotum impressicolle Arrow	***Metarhizium anisopliae*** (Metschnikoff) Sorokin; (Hypocreales: Clavicipitaceae)	**TAIWAN**	1914	*(ex Hawaii USA)* Numbers of scarabs greatly reduced in fields where spores were released.	Native	199, 200
Dermolepida albohirtum (Waterhouse); Greyback cane beetle	***Metarhizium anisopliae*** (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 *Rhabdoscelus obscurus* (Boisduval), the New Guinea sugarcane weevil, killed by this fungus.	Native	196
Lepidiota pruinosa Wied., and ***Leucopholis irrorata*** Chevrolat; white grubs in sugar cane	***Metarhizium anisopliae*** (Metschnikoff) Sorokin; (Hypocreales: Clavicipitaceae)	**PHILIPPINES**	1928	*(ex Queensland, Australia)* Not effective control and “undoubtedly already present.”	Native	162
Lepidiota sp., ***Anoplognathus*** sp., and other spp.; white grubs in sugar cane	***Beauveria brongniartii*** (Saccardo) Petch [= *Botrytis tenella* 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)						
Oryctes rhinoceros (L.); Asiatic or Coconut rhinoceros beetle	***Metarhizium anisopliae*** (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
Papuana huebneri (Halmahera); Taro beetle	***Metarhizium anisopliae*** (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
Phyllophaga smithi (Arrow) [= *Lachnosterna smithi* (Arrow); = *Clemora smithi* (Arrow); = *Phytalus smithi* Arrow]; white grub in sugar cane	***Beauveria bassiana*** (Balsamo) Vuillemin [= *Beauveria densa* (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
	Metarhizium anisopliae (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						
Otiorhynchus nodosus (Müller), and ***O. arcticus*** (Fabricius)	***Metarhizium anisopliae*** (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 *M. anisopliae* in 40% of samples.	Native	139, 140
Sitona discoideus Gyllenhal; Sitona weevil	***Beauveria bassiana*** (Balsamo) Vuillemin; (Hypocreales: Cordycipitaceae)	**AUSTRALIA**	1984	*(ex Montpellier, France)* Released in southern Australia. No infections ever found.	Introduced	5
DIPTERA: CULICIDAE						
Aedes polynesiensis Marks	***Coelomomyces stegomyiae*** Keilin; (Blastocladiales: 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						
Lymantria dispar (L.); Gypsy moth	***Entomophaga maimaiga*** 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)						
Lymantria dispar (L.) (continued)	***Entomophaga maimaiga*** 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 *L. dispar* 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; *E. maimaiga* 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 *L. dispar* 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						
Eriophyes sheldoni (Ewing): Citrus bud mite	***Hirsutella thompsonii*** Fisher var. *vinacea* 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
Eriophyes sheldoni (Ewing); Citrus bud mite; and ***Phyllocoptruta oleivora*** (Ashmead); Citrus rust mite	***Hirsutella thompsonii*** Fisher var. *synnematosa* 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						
Mononychellus tanajoa (Bondar); Cassava green mite	***Neozygites tanajoae*** Delalibera, Hajek & Humber (prev. referred to as *Neozygites floridana* (Weiser & Muma) Remaudiére & Keller); (Neozygitales: Neozygitaceae)	**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						
Dichroplus maculipennis (Blanchard), ***D. elongatus*** (Giglio-Tos), ***D. pratensis*** Bruner, and ***Scotussa lemniscata*** Stål	***Paranosema locustae*** (Canning) [= *Nosema locustae* Canning; = *Antonospora locustae* (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						
Culex pipiens quinquefasciatus Say [= *C. pipiens fatigans* Wiedemann; = *C. fatigans* Wiedemann]	***Vavraia culicis*** (Weiser) Weiser [= *Pleistophora* / *Plistophora culicis* Weiser]; (Clade 5)	**NAURU** (in Micronesia)	1967	*(ex Lagos, Nigeria)* Establishment not confirmed.	Native	107
LEPIDOPTERA: CRAMBIDAE						
Ostrinia nubilalis (Hübner); European corn borer	***Nosema pyrausta*** (Paillot) [= *Perezia pyraustae* Paillot; = *Glugea pyraustae* (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						
Lymantria dispar (L.); Gypsy moth	***Nosema portugal*** Maddox & Vávra [= *Microsporidium* 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
	Endoreticulatus schubergi (Zwölfer) A. Cali & El Garhy [Reported as *Vavraia* sp.]; (Clade 4, Branch B)	**USA: Maryland**	1986	*(ex Portugal)* Not established.	Introduced	91, 92, 121
	Nosema lymantriae Weiser; (Clade 4, Branch A)	**USA: Illinois**	2008, 2010	*(ex Bulgaria)* Not established.	Introduced	151
	Vairimorpha disparis (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						
Culex tarsalis Coquillett; Western encephalitis mosquito	***Lagenidium giganteum*** 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						
Scapteriscus abbreviatus Scudder, ***S. borelli*** Gigli-Tos, and ***S. vicinus*** Scudder; Mole crickets	***Steinernema scapterisci*** 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. *S. borelli* more susceptible than *S. vicinus*, but both can be controlled.	Introduced	53, 145
Scapteriscus didactylus (Latreille) and ***S. abbreviatus*** Scudder; Mole crickets	***Steinernema scapterisci*** Nguyen & Smart; (Rhabditida: Steinernematidae)	**PUERTO RICO**	2001-04	*(ex Florida USA; originally Uruguay)* Establishment confirmed. *S. didactylus* in Puerto Rico about as susceptible as *S. borellii* is in Florida, but *S. abbreviatus*, for unknown reasons, is less susceptible.	Introduced	53, 111
COLEOPTERA: SCARABAEIDAE						
Oryctes rhinoceros (L.); Asiatic or Coconut rhinoceros beetle	***Rhabditis*** 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)						
Oryctes rhinoceros (L.) (continued)	***Rhabditis*** sp. nr. ***maupasi***; (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						
Sitona discoideus Gyllenhal; Sitona weevil	***Heterorhabditis bacteriophora*** Poinar [= *H. heliothidis* (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.	***Romanomermis culicivorax*** Ross & Smith [= *Reesimermis nielseni* Tsai & Grundmann]; (Mermithida: Mermithidae)	**AZERBAIJAN (USSR)**	ca 1990	*(source unknown) Aedes caspius* (Pallas), *Culex modestus* Ficalbi, *C. theileri* Theobald, *Uranotaenia unguiculata* 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
	Romanomermis iyengari Welch; (Mermithida: Mermithidae)	**AZERBAIJAN (USSR)**	ca 1990	*(source unknown; originally from India) Anopheles sacharovi* Favre and *Culex theileri* 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]						
Anopheles gambiae Giles	***Romanomermis iyengari*** Welch; (Mermithida: Mermithidae)	**BENIN** (in west Africa)	2011	*(source unknown; originally from India)* Releasing monthly suppressed *A. gambiae*. Longer term establishment not reported.	Native	1
Aedes spp. and ***Ochlerotatus*** spp.; 10 species total	***Romanomermis culicivorax*** Ross & Smith [= *Reesimermis nielseni* 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.	***Romanomermis iyengari*** Welch; (Mermithida: Mermithidae)	**CUBA**	1991	*(source unknown; originally from India)* High levels of parasitism of *A. albimanus* Wiedemann, *C. nigripalpus* Theobald, *C. quinquefasciatus* Say, *Uranotaenia sapphirina* (Osten Sacken); and reduced host populations. At some sites *R. iyengari* was established for up to 5 months.	Native	153, 165
Anopheles nyssorhynchus albimanus Wiedemann	***Romanomermis culicivorax*** Ross & Smith [= *Reesimermis nielseni* 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
Anopheles nyssorhynchus albimanus Weidemann and ***A. punctipennis*** (Say)	***Romanomermis culicivorax*** Ross & Smith [= *Reesimermis nielseni* 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
Anopheles dthali Patton, ***A. superpictus*** Grassi, ***A. sergentii*** (Theobald), ***A. turkhudi*** Liston, and ***A. culicifacies*** Giles	***Romanomermis culicivorax*** Ross & Smith [= *Reesimermis nielseni* 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]						
Anopheles pseudopunctipennis Theobald	***Romanomermis iyengari*** 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
Culex pipiens quinquefasciatus Say and ***Aedes aegypti*** (L.)	***Octomyomermis muspratti*** 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.	***Romanomermis iyengari*** 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 (*Anopheles superpictus* Grassi, *A. pulcherrimus* Theobald, *A. hyrcanus* group). Long term establishment unknown.	Native	153, 191
	Romanomermis culicivorax Ross & Smith [= *Reesimermis nielseni* 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 (*Anopheles superpictus* Grassi, *A. pulcherrimus* Theobald, *A. hyrcanus* 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]						
Culex pipiens quinquefasciatus Say	***Romanomermis culicivorax*** Ross & Smith [= *Reesimermis nielseni* 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
Aedes polynesiensis Marks and ***Ae. aegypti*** (L.)	***Romanomermis culicivorax*** Ross & Smith [= *Reesimermis nielseni* 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
Anopheles freeborni Aitken and ***Culex tarsalis*** Coquillett	***Romanomermis culicivorax*** Ross & Smith [= *Reesimermis nielseni* 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
Anopheles punctipennis (Say), ***A. crucians*** Weidemann, ***Aedes vexans*** (Meig.), ***Culex restuans*** Theobald, and ***C. pipiens*** L.	***Romanomermis culicivorax*** Ross & Smith [= *Reesimermis nielseni* 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.	***Romanomermis iyengari*** Welch; (Mermithida: Mermithidae)	**UZBEKISTAN (USSR)**	ca 1990	*(source unknown; originally from India)* *Anopheles martinius* Schingarev, *A. hyrcanus* group, *Culex modestus* Ficalbi were parasitized after releases. *Aedes caspius* (Pallas) was not. Infection from 9-67% and only effective in water bodies with low salt content.	Native	153, 158
LEPIDOPTERA: EREBIDAE						
Lymantria dispar (L.); Gypsy moth	***Hexamermis*** 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						
Sirex noctilio F.; European woodwasp, Sirex wasp	***Deladenus siricidicola*** Bedding [= *Beddingia siricidicola* (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 *Sirex*.	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)						
Sirex noctilio F. (continued)	***Deladenus siricidicola*** Bedding (continued)	**AUSTRALIA: Victoria**	1971	*(ex Tasmania and other locations)* 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 *radiata* pines inoculated in the Green Triangle in 1987 alone. With over 20 years of *in vitro* production, strain lost virulence resulting in replacement of strain used for releases.	Introduced	14, 76
		URUGUAY	1987	*(ex New Zealand)* Established, yielding 18% parasitism.	Introduced	21, 157, 166
		BRAZIL	1989-90, 1994	*(ex Australia)* 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 *S. noctilio* populations.	Introduced	14, 84, 85, 86
		SOUTH AFRICA: Western Cape	1995-96	*(ex Australia)* 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	*(ex Australia)* 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)						
Sirex noctilio F. (continued)	***Deladenus siricidicola*** Bedding (continued)	**SOUTH AFRICA: Mpumulanga and Limpopo**	2010+, 2012+	*(ex South Africa, from earlier Kamona release sites)* 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, +	*(ex Brazil)* 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 *Sirex* attacks occur.	Introduced	11, 49, 83
		ARGENTINA: Patagonia	1999, 2001-06	*(ex Brazil and New Zealand)* 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 *Sirex*.	Introduced	35, 83, 98, 99, 100
		CHILE	2006-09	*(ex Brazil and New Zealand)* Released Encruziliada 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	*(Likely origin)* Results from introduction	Pest origin	References
LEPIDOPTERA: ZYGAENIDAE						
Harrisina brillians Barnes & McDunnough; Western grape skeletonizer	***Harrisina brillians granulovirus* (HbGV)**; (Baculoviridae: *Betabaculovirus*)	**USA: California**	Early 1950s	*(probably from Mexico and/or Arizona USA)* 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						
Ostrinia nubilalis (Hübner); European corn borer	***Nosema pyrausta*** (Paillot) [= *Perezia pyraustae* Paillot; = *Glugea pyraustae* (Paillot)]; (Microsporidia: Clade 4, Branch A)	**USA: New Jersey**	1949	*(probably from Europe)* 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						
Lymantria dispar (L.); Gypsy moth	***Lymantria dispar multiple nucleopolyhedrovirus* (LdMNPV)**; (Baculoviridae: *Alphabaculovirus*)	**USA: northeast**	1907	*(probably from Europe)* 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 *E. maimaiga* became established, caused epizootics in high density, tree-defoliating populations of *L. dispar*, 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	*(Likely origin)* Results from introduction	Pest origin	References
LEPIDOPTERA: EREBIDAE (continued)						
Lymantria dispar (L.) (continued)	***Entomophaga maimaiga*** Humber, Shimazu & Soper; (Entomophthorales: Entomophthoraceae)	**USA: northeast**	1989	*(from Japan; apparently sometime after 1971; not same strain as 1985-86 releases; very unlikely from 1910-11 releases)* 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	*(source unknown; originally from Japan)* 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						
Sirex noctilio F.; European woodwasp, Sirex wasp	***Deladenus siricidicola*** Bedding [= *Beddingia siricidicola* (Bedding)]; (Nematoda: Rhabditida: Neotylenchidae)	**NEW ZEALAND: North Island**	1962	*(source unknown; Europe?)* Thought to have arrived with host. Attributed with being the most important agent controlling host on the North Island, where the *Deladenus* strain that sterilizes the female (infesting the eggs before oviposition) was first found in introduced *Sirex* populations.	Introduced	13, 213, 215

PEST ORDER: FAMILY Pest species	Pathogen/Nematode; (Group)	Country or region of first observation	Year found	*(Likely origin)* Results from introduction	Pest origin	References
HYMENOPTERA: SIRICIDAE (continued)						
Sirex noctilio F. (continued)	***Deladenus siricidicola*** Bedding (continued)	**NEW ZEALAND: North Island**	1971	*(source unknown)* 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	*(source unknown; Europe?)* Non-sterilizing strain found in *S. noctilio* in Ontario 2007-08 and 2011 in New York and Pennsylvania. Believed brought in by *S. noctilio* (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 *S. noctilio*, but not in all trees or host adults.	Introduced	105, 203
HYMENOPTERA: DIPRIONIDAE						
Gilpinia hercyniae (Hartig) [= *Diprion hercyniae* Hartig]; European spruce sawfly	***Gilpinia hercyniae nucleopolyhedrovirus* (GhNPV)**; (Baculoviridae: *Gammabaculovirus*)	**CANADA and USA**	1936	*(probably from Europe)* 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	*(Likely origin)* Results from introduction	Pest origin	References
HYMENOPTERA: DIPRIONIDAE (continued)						
Gilpinia hercyniae (Hartig) (continued)	***Gilpinia hercyniae nucleopolyhedrovirus* (GhNPV)**; (continued)	**UK: WALES**	1970/71	*(probably from Europe)* Spread from small epicenter and controlled pest outbreak by 1974.	Introduced	41, 50
HYMENOPTERA: FORMICIDAE						
Solenopsis invicta Buren; Red imported fire ant	***Thelohania solenopsae*** Knell, Allen & Hazard; (Microsporidia: Clade 3)	**USA: Florida**	1996	*(from South America)* 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

APPENDIX I: Taxonomic List of the Pathogens and Nematodes[1]

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 Blastocladiales

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 Myriangiales

Family Myriangiaceae

Myriangium duriaei

Order Pleosporales
Family Tubeufiaceae

Podonectria coccophila

Class Sordariomycetes
Order Hypocreales[2]

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. *synnematosa*
Hirsutella thompsonii var. *vinacea*

Domain Eukarya (continued)

Phylum Microsporidia
Clade 2
Paranosema locustae
Clade 3
Thelohania solenopsae
Clade 4
Branch A[3]
Nosema lymantriae
Nosema portugal
Nosema pyrausta
Vairimorpha disparis
Branch B[3]
Endoreticulatus schubergi
Clade 5
Vavraia culicis

Supergroup SAR[4] (includes stramenopiles, alveolates and *Rhizaria*)
Phylum Heterokontophyta (Heterokonta; Stramenopiles)
Class Peronosporomycetes (Oomycota)
Order Lagenidiales
Family Lagenidiaceae
Lagenidium giganteum

Kingdom Animalia
Phylum Nematoda[5]
Class Enoplea
Order Mermithida
Family Mermithidae
Hexamermis 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

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[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 martinius
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
Phyllocoptruta 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						
Hoplochelus marginalis (Fairmaire); Sugarcane white grub	***Beauveria hoplocheli*** I. Robène-Soustrade & S. Nibouche [previously reported as *B. brongniartii*]; (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
	Metarhizium anisopliae (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

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