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The risk of classical biological control in Florida

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Abstract

Classical biological control in Florida dates from 1899, when *Rodolia cardinalis* (Mulsant) was introduced and controlled an infestation of the adventive (= nonindigenous) species *Icerya purchasi* Maskell. We list 60 invertebrates (59 insects and one nematode) imported into and established in Florida up until and including 2003. No vertebrates have been imported and established for classical biological control. All targets of successful introductions except one were adventive pest insects and weeds. The exceptional target was a widespread aphid, whose introduced biological control agent had no obvious effect. Using many sources of information, we consider the effects, both potential and realized, of established classical biological control agents, on non-target species in Florida. Our goal was to provide a substantiated record and an example analysis. Florida, with high numbers of invasive species, is a microcosm of worldwide classical biological control. We recognized six levels of host range of agents and concluded that 24 agents potentially have native species in their host range. Our analysis suggests that fewer than 10 introduced agents are likely to have produced population changes in non-target organisms and, of these, fewer than four are likely to have produced substantial population changes. No species has had a documented substantial effect on a non-target species in Florida. Such evidence might accrue in future, however, if searched for diligently.

Keywords: Biocontrol; Non-target effects; History of biocontrol; Animal biocontrol agents; Invertebrate biocontrol agents; Insect biocontrol agents; Nematode biocontrol agents

1. Introduction

The record of arrival of insect species in Florida is relatively well known compared with other regions (e.g., Frank and McCoy, 1992, 1993, 1994, 1995a,b; Boender, 1995; Thomas, 1995; Frank et al., 1997). A much cited paper by Bennett (1993) [see other contributions in Florida Entomologist 72, 1–64; 73, 1–119; 74, 1–59; 75, 1–83; 76, 1–113; 77, 1–84; 78, 1–55, available free on the internet <http://www.fcla.edu/FlaEnt//> by courtesy of FES] was the first to consider the potential effects of these species on the native biota of Florida. Other relatively early papers on non-target effects of classical biological control agents were by Howarth (1983, 1991), Pimentel et al. (1984), Samways (1988, 1994), and several other authors listed in Hawkins and Marino (1997). Subsequently, interest in non-target effects of biological control agents has risen sharply, statewide, nationally, and internationally, and classical biological control efforts have come under increasingly sharp criticism for having unwanted non-target effects.

The latest review of the insect species (deliberately) introduced (Frank and McCoy, 1990) into Florida dates from 1993 (Frank and McCoy, 1993). Almost all introductions were classical biological control agents. In this review, we list and discuss classical biological control agents that were introduced and established in Florida up to and including 2003, ignoring those species not considered established (see Frank and McCoy, 1993), and the targets of those agents. We consider both potential and realized non-target effects of these. Our goal is to provide a substantiated record, to eliminate as much speculation as is currently possible, and to provide an example of this

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type of analysis. Although our emphasis is on Florida's record, the region is a microcosm for worldwide classical biological control.

2. Materials and methods

We reduced and corrected an earlier list of insects introduced into Florida (Frank and McCoy, 1993) to those that established in Florida as classical biological control agents, and incorporated taxonomic nomenclatural changes. We then added later records up to and including 2003 as well as records for animals other than insects. Finally, we searched for evidence of non-target effects of introduced biological control agents in Florida by examining the biological control literature (e.g., Bennett, 1993; Follett and Duan, 2000; Howarth, 2000; Lynch and Thomas, 2000; Wajnberg et al., 2001; Van Driesche and Reardon, 2004), questioning colleagues, and searching databases (entomological literature databases, the internet, and the ROBO database of USDA-ARS).

We categorized the classical biological control agents by host range, recognizing six levels of specialization, but we recognize that this categorization is imperfect given the unstable, developing classification of most insect taxa.

Large differences in the amount of pre-release testing of biological control agents of weeds and of arthropods caused us to use different criteria to define host range. We defined host ranges for weed biological control agents as the composite of the potential host range as determined in pre-release laboratory testing and the realized host range as determined in the field based on the ability of the host to support agent development. We defined host ranges for arthropod biological control agents based on all available records, as pre-release host range testing of these agents was seldom if ever a requirement for introduction until a decade ago (see Van Driesche and Bellows, 1996). Unpublished data compiled at the Florida Department of Agriculture, Division of Plant Industry, Gainesville were particularly useful for this. We included host/prey records from all parts of the world, except when it could be shown that the host/prey does not occur in Florida; even so, such records were used to assess the range of host specialization.

We categorized the targets of the classical biological control agents by origin. Any species established in nature in a specified area is either native or adventive [i.e., species that are not native, and, therefore, arrived in the region of interest from elsewhere (Frank and McCoy, 1990)] to that area. The word adventive includes immigrant and introduced, so does not specify the means of arrival, although the distinction between immigrant and introduced species clearly is important in assessing potential effects on native biotas (Ruesink et al., 1995). For historico-political reasons, species believed to be present in Florida at the time of arrival of Columbus in the New World (AD 1492) are considered native, and any that are believed to have arrived after that date as adventive. Assignment of labels as native and adventive requires inferences to be made from other evidence, however, as Florida's insect fauna in AD 1492 was undocumented.

We modeled our analysis of non-target effects after a paper by Stiling and Simberloff (2000), in which they addressed the fundamental questions of what is the host range of released natural enemies? what portion of the native biota is susceptible to non-target effects? how frequent are non-target effects of biological control agents? and what are the strengths of the non-target effects (Stiling and Simberloff, 2000, pp. 32–33)? We considered only agents introduced to, and established in, Florida for biological control purposes, although we acknowledge that agents introduced elsewhere may subsequently have immigrated to Florida (e.g., McEvoy and Coombs, 2000). We considered only direct non-target, although we acknowledge the potential importance of indirect effects (e.g., Neuenschwander and Markham, 2001; Hoddle, 2004). We considered only agents that became established, although we acknowledge that agents can have non-target effects whether they establish or not (e.g., Hawkins and Marino, 1997; Lynch and Thomas, 2000; Lynch et al., 2002), and that agents that do establish can, in some ways, potentially cause less harm (see Hawkins et al., 1999). More than 150 agents have been introduced in classical biological control programs in Florida, and agents that have failed to establish on their targets include herbivorous and predacious species with relatively broad potential host ranges (Frank and McCoy, 1993, 1994). Finally, in our assessment we do not always distinguish between agents introduced against plant or animal target species, although we acknowledge that the two kinds of agents may tend to differ in rates of establishment, chances for ecological segregation, method of host selection, and other ways that influence the likelihood of non-target effects (e.g., Frank and McCoy, 1993; Hoddle, 2004; Van Driesche, 2004). Such issues will be addressed elsewhere (Frank and McCoy, in preparation).

3. Results and discussion

3.1. Established biological control introductions and their targets

The current list of established biological control introductions includes 59 insect species and one nematode (Table 1). Fifty-nine insect species, however, are less than 0.5% of the estimated 12,500 insect species in Florida (Frank and McCoy, 1995b). In contrast, it is estimated that 2.4% of south Florida's birds, 16% of fishes, 22% of amphibians, 23% of mammals, 27% of plants, and 42% of reptiles, are adventive, many of them (deliberately) introduced (Frank and McCoy, 1995a; Frank et al., 1997). We consider each of the species below, bringing up-to-date the information on those species reviewed previously (Frank and McCoy, 1993) and newly reviewing those species introduced since the previous review.

Table 1
Established biocontrol introductions

Aceratoneuromyia indica (Silvestri) (Hymenoptera: Eulophidae), released in FL in 1984, from India (via Colombia), vs Caribbean fruit fly, *Anastrepha suspensa* (Loew) (Diptera: Tephritidae), a target native to the W. Indies (Baranowski et al., 1993; Ovruski et al., 2000). *Specificity*. Its host in India is *Bactrocera dorsalis* (Hendel), a tephritid pest of fruits; here assumed capable of attacking several tephritid genera whose larvae infest fruits.

Aganaspis daci (Weld) (Hymenoptera: Figitidae) [synonym *Trybliographa daci*], released in FL in 1979, from Indo-Australian region (via France) vs Caribbean fruit fly, *Anastrepha suspensa* (Loew) (Diptera: Tephritidae), which is native to the W. Indies; established (Baranowski et al., 1993; Ovruski et al., 2000). *Specificity*. Not monophagous, but attacks other tephritid genera whose larvae infest fruits.

Agasicles hygrophila Selman and Vogt (Coleoptera: Chrysomelidae), released in FL in 1965, from Argentina, vs alligatorweed, *Alternanthera philoxeroides* (Martius) Grisebach (Caryophyllales: Amaranthaceae), a target native to S. America. *Specificity*. Tested vs 14 plant species in eight families; this plus field observations, show it is essentially monophagous on alligatorweed (Buckingham, 1994; Jackman, 2002).

Ageniaspis citricola Logvinovskaya (Hymenoptera: Encyrtidae), released in FL in 1994, from Thailand (via Australia), vs citrus leafminer, *Phyllocnistis citrella* Stainton (Lepidoptera: Gracillariidae); achieved 85% parasitism of its host at some sites by October 1995 (Hoy and Nguyen, 1997; Pomerinke and Stansly, 1998). *Specificity*. Tests in Australia using larvae of the only native Australian species of *Phyllocnistis*, three other genera of Gracillariidae, various other lepidopterous families, and even some Diptera, pointed to monophagy of *A. citricola* (Neale et al., 1995). But in the field in FL it was once seen to attack mahogany leafminer, *Phyllocnistis meliacella* Becker (Pomerinke and Stansly, 1998), a pest species native to FL and other parts of the range of mahogany. No information on attack on other native *Phyllocnistis* species in FL.

Alabagrus stigma (Brullé) (Hymenoptera: Braconidae) [synonym *Agathis stigmatera* (Cresson)], released in FL in 1932, from Peru, vs sugarcane borer, *Diatraea saccharalis* (F.) (Lepidoptera: Pyralidae), a target native to the American tropics. *Specificity*. Attacks several species of pyralid stem borers in rice, corn, and sugarcane (Sharkey, 1988). These include in Mauritius *Chilo sacchariphagus* (Bojer) (Ganeshan and Rajabalee, 1997) and in TX *Eoreuma loftini* (Dyar) (Meagher et al., 1998), but in FL only the pest *D. saccharalis* is known as a host, making this parasitoid monophagous. A catalog entry (Shenefelt, 1970) of *Spodoptera frugiperda* (J.E. Smith) as a host, attributed to Myers (1932), was discounted by Sharkey (1988) because no such statement was made by Myers (1932).

Amitus hesperidum Silvestri (Hymenoptera: Platygastridae), released in FL in 1976, from India (via Mexico and in part via TX), vs citrus blackfly, *Aleurocanthus woglumi* Ashby (Homoptera: Aleyrodidae), a target native to Asia (Nguyen et al., 1983; Thompson et al., 1987). *Specificity*. Not known to attack any non-target species (G.A. Evans, personal communication) so here judged monophagous.

Amynothrips andersoni O'Neill (Thysanoptera: Paleothripidae), released in FL in 1967–1972, from Argentina, vs alligatorweed, *Alternanthera philoxeroides* (Martius) Grisebach (Caryophyllales: Amaranthaceae), a target native to S. America; established in FL, but at low population densities (Buckingham, 1994). *Specificity*. Testing vs 21 plants in five families, together with field collections, showed development only on alligatorweed and the S. American *Alternanthera hassleriana* Chodat (O'Neill, 1968; Maddox, 1973). In effect, it is monophagous in FL.

Anagyrus antoninae Timberlake (Hymenoptera: Encyrtidae), released in FL in 1954, from TX (but of Hawaiian origin although native to Asia), vs Rhodesgrass mealybug, *Antonina graminis* (Maskell) (Homoptera: Pseudococcidae), became established, but by the late 1980s was not found in a survey by F.D. Bennett, may have been displaced competitively by later-introduced parasitoids of this same pest, and may no longer occur in FL (Bennett, 1994). The target is native to Asia. *Specificity*. No information about hosts other than *A. graminis*, so we assume monophagy.

Anagyrus kamali Moursi (Hymenoptera: Encyrtidae), released in FL in 2002, from China (via Puerto Rico) vs pink hibiscus mealybug, *Maconellicoccus hirsutus* (Green) (Homoptera: Pseudococcidae). The target is native to Asia and was detected in FL in 2002, having already infested Puerto Rico and some other Caribbean islands. *Specificity*. In trials in Puerto Rico, it developed only in *M. hirsutus* among nine other coccids tested in the laboratory (Sagarra et al., 2001). But in Asia is known also from *Ferrisia virgata* (Cockerell), which is an adventive pest in FL, and indet. spp. of *Nipaecoccus* and *Pseudococcus* (Noyes and Hayat, 1994; Michaud and Evans, 2000). We assume it is monophagous in FL The *Nipaecoccus* spp. in FL are adventive pests, from which *A. kamali* is not reported (G.S. Hodges, personal communication).

Aphelinus gossypii Timberlake (Hymenoptera: Aphelinidae), released in FL in 1969, from India, vs *Aphis gossypii* Glover (Hymenoptera: Aphididae) (Denmark and Porter, 1973; Frank and McCoy, 1993). That introduction was presumed by Yokomi and Tang (1995) to have been successful, because they found specimens from *A. gossypii* on citrus in FL. *Specificity*. Evans and Stange (1997) report *A. gossypii* from five aphid spp. in FL: *A. craccivora* Koch, *Aphis gossypii*, *Brachycaudus helichrysi* (Kaltenbach), *Rhopalosiphum maidis* (Fitch), and *Toxoptera aurantii* (Boyer de Fonscolombe), all are adventive pests in FL (S.E. Halbert, personal communication).

Aphytis holoxanthus DeBach (Hymenoptera: Aphelinidae), released in FL in 1960, from Hong Kong (via Israel, NJ, and CA), vs "Florida red scale", *Chrysomphalus aonidum* (L.) (Homoptera: Diaspididae), a major pest of citrus, which, despite its vernacular name, is native to Asia. The target's name was recently found to be a senior synonym of *Chrysomphalus ficus* Ashmead, a widespread pest in several continents, thus expanding the known list of natural enemies to include those of *C. ficus*. The factitious host in laboratory cultures of *A. holoxanthus* was *Aspidiotus nerii* Bouché (Homoptera: Diaspididae), a species with widespread distribution around the world, not clearly native to FL In the field in FL, the parasitoid also has been found to attack *Selenaspidus articulatus* (Morgan) (Homoptera: Diaspididae), a species first reported in FL in 1909 and probably of Neotropical origin. *Specificity*. In the field in FL, it has been very effective vs *C. aonidum*, but is rarely reared from the two non-target hosts (G.A. Evans, personal communication). It was highly efficient in reducing populations of *C. aonidum* and seemed to have replaced (on that host) a native parasitoid, *Pseudhomalopoda prima* Girault (Hymenoptera: Encyrtidae) (Selhime et al., 1969). However, *P. prima* is still the dominant parasitoid of *Aculaspis morrisonorum* Kosztarab on southern red cedar in FL (Bennett, 1993). The conclusion must be that *P. prima* was outcompeted on *C. aonidum* (an abnormal host) by *A. holoxanthus* (a specialist), but is alive and well on its normal hosts. Claims cited by Lynch and Thomas (2000) that *P. prima* (a native species) was displaced by introduction of *A. holoxanthus* into FL fail to tell the whole story and thus give the erroneous notion that *P. prima* has been extirpated.

Aphytis sankarani Rosen and DeBach (Hymenoptera: Aphelinidae), first released in FL in 2002, from Thailand vs *Pseudaulacaspis cockerelli* (Cooley) (Homoptera: Diaspididae); has become established (H. B. Glenn, personal communication). *Specificity*. *P. cockerelli* is the only known host (G.A. Evans, personal communication).

(*continued on next page*)

Table 1 (*continued*)

Arcola malloi (Pastrana) (Lepidoptera: Pyralidae) [synonym *Vogtia malloi* Pastrana], released in FL in 1971, from Argentina, vs alligatorweed, *Alternanthera philoxeroides* (Martius) Grisebach (Caryophyllales: Amaranthaceae), target native to S. America. *Specificity*. Testing vs 36 plant spp. in 6 families showed complete development only on alligatorweed (Buckingham, 1994). Should be considered monophagous.

Boreioglycaspis melaleucae Moore (Homoptera: Psyllidae), released in FL in 2002 vs melaleuca, *Melaleuca quinquenervia* (Cavanilles) S.T. Blake (Myrtaceae), a target native to Australia. *Specificity*. although it attacks an additional species of *Melaleuca* in Australia, that species does not occur in FL In quarantine testing, caused minor damage to two species of the genus *Callistemon* (bottlebrush tree), non-native trees grown as ornamentals (Wineriter et al., 2003). The genus *Callistemon* is scarcely distinct from *Melaleuca*, and may yet be integrated within the latter genus. Because of laboratory feeding damage (but not development) on *Callistemon*, we assume it is monophagous in FL.

Chilocorus circumdatus (Schoenherr) (Coleoptera: Coccinellidae) [other writers give the author name as Gyllenhal], released in FL in 1996, from SE Asia (via Australia where it is adventive) vs citrus snow scale, *Unaspis citri*, and is established (H.W. Browning, personal communication, M.C. Thomas, personal communication). *Specificity:* is known in Australia to attack *U. citri* and *Aspidiotus nerii* (Bouché) (Houston, 1991), both of which occur in FL as adventive pests. Lacking other information, we assume that in FL it attacks the same prey as in Australia, and the hosts in FL are adventive, pest, armored scales.

Cirrospilus ingenuus Gahan (Hymenoptera: Eulophidae) [synonym *C. quadristriatus* Subba Rao and Ramamani], released in FL in 1994 from Asia (via Australia) vs citrus leafminer, *Phyllocnistis citrella* Stainton (Lepidoptera: Gracillariidae); was later shown to be a facultative hyperparasitoid of *Ageniaspis citricola* (see above), which is a valuable biocontrol agent of citrus leafminer (Hoy and Nguyen, 1994; Smith and Hoy, 1995; LaSalle et al., 1999). *Specificity*. Earlier imported from Asia into Australia, targeted vs citrus leafminer. In Australian quarantine, 19 insect spp. were evaluated as potential hosts, and none (including other gracillariid species) was parasitized by *C. ingenuus* (Neale et al., 1995; Hoy and Nguyen, 2003). However, synonymy of *C. quadristriatus* was established in 1995 (Schauff et al., 1998; Evans, 1999). Later, Chinese *Cirrospilus* spp. were revised, and one record of *C. ingenuus* was found from a lyonetiid leafminer, although all the others were from citrus leafminer (Zhu et al., 2002). Questionable records are from a pest weevil in India (Hoy and Nguyen, 1994), an agromyzid fly in Jordan (Massa et al., 2001), and (above) as a hyperparasitoid of *Ageniaspis citricola*. If all of these records are correct, the host range includes members of 4 insect orders, but of few species within each order. There is yet no documentation of non-target effects in FL.

Coccinella septempunctata L. (Coleoptera: Coccinellidae), released in FL in 1958 and subsequently, from India, as a biocontrol agent for various pest aphids, and did ultimately become established in FL (Frank and McCoy, 1993), now widespread in FL (Peck and Thomas, 1998). Uncertain whether the presence of this species anywhere in North America resulted from a biological control introduction, or whether it resulted from immigration (Angalet et al., 1979; Gordon, 1985). Because biological control practitioners in the 1950s did try to introduce it, we will include it in this list—knowing that its listing here will lead to its scrutiny as a polyphagous predator. *Specificity*. Not prey-specific; with circumstantial evidence to suggest that in the northern USA its presence may have led to a reduction in populations of the native coccinellid *C. novemnotata* Herbst (Wheeler and Hoebeke, 1995) and perhaps of other coccinellid species (Elliott et al., 1996). Laboratory studies in northern USA showed that larvae of the native coccinellid *Coleomegilla maculata* (DeGeer) are not disadvantaged by competition with *C. septempunctata* larvae at high prey density, but *C. maculata* may in some, but not all, ways be relatively disadvantaged at low prey density (Obrycki et al., 1998). In contrast, in WV apple orchards, invasion by *Harmonia axyridis* may be allowing native coccinellids to become more abundant on apple than when *C. septempunctata* was the dominant coccinellid (Brown, 2003). The situation in FL has not been investigated, but evidence from elsewhere shows that several aphid genera and species serve as prey. Possibly, without evidence in FL, based upon reports from other parts of the USA, it may outcompete native coccinellids food. Other possibilities without evidence are that (1) populations of non-target native aphids have declined, and (2) populations of adventive pest aphids have declined, as a result of the introduction (if really it was an introduction).

Coccobius fulvus (Compere and Annecke) (Hymenoptera: Aphelinidae) [synonym: *Physcus fulvus*], released in FL in 1998 from Thailand as a biocontrol agent for cycad aulacaspis scale, *Aulacaspis yasumatsui* Takagi (Homoptera: Diaspididae) (Howard and Weissling, 1999; H.B. Glenn, personal communication). Target is native to Asia. *Specificity*. Has also been introduced into Japan as a biocontrol agent for arrowhead scale, *Unaspis yanonensis* (Kuwana), not monophagous. Elsewhere reported from *Pinnaspis strachani* (Cooley) (Homoptera: Diaspididae); although that host is a pest in FL, and of wide distribution elsewhere (so its origin is unclear), the parasitoid has not yet been reported from it in FL (G.A. Evans, personal communication).

Coelophora inaequalis (F.) (Coleoptera: Coccinellidae), released in FL in 1939, from Hawaii (via Puerto Rico), vs yellow sugarcane aphid, *Sipha flava* (Forbes) (Homoptera: Aphididae). Target is a pest of sugarcane in the W. Indies and FL. However, because it was originally described from the eastern USA, and because we have discovered no taxononomic consideration of its native range and subsequent expansion, we have no option but to consider it also native to FL; most likely it fed on various wild grasses and adapted to sugarcane. *Specificity*. Now seems to play no role in control of aphids in sugarcane in FL (Hall and Bennett, 1994), but is present in FL (Gordon, 1985; Bennett et al., 1990; Hall and Bennett, 1994), presumably feeding on other aphid prey such as *Aphis craccivora* Koch, *A. gossypii* Glover, *A. nerii* Boyer de Fonscolombe, *Hydaphis erysimi* (Kaltenbach), *Myzus persicae* (Sulzer), *Neophyllaphis araucariae* Takahashi, *Rhopalosiphum maidis* (Fitch), *Thoracaphis fici* (Takahashi), *Toxoptera aurantii* (Boyer de Fonscolombe), and *Toxoptera citricida* (Kirkaldy) (Gordon, 1985), all of which are adventive pests or are not yet present in FL (S.E. Halbert, personal communication). No information about predation on native FL aphids.

Cotesia flavipes Cameron (Hymenoptera: Braconidae) [synonym *Apanteles flavipes*], released in FL in 1963, from India (via Delaware), vs sugarcane borer, *Diatraea saccharalis* (F.) (Lepidoptera: Pyralidae). Has been imported into various parts of the Americas as a biocontrol agent for *D. saccharalis*, with general success barring evidence of subsequent physiological host-resistance in some areas. Natural hosts in India are other stem-boring Pyralidae, so not monophagous. Target native to American tropics. *Specificity*. Was also released elsewhere in the USA and has been reported also from *D. grandiosella* Dyar and *D. lineolata* (Walker) but not *D. considerata* Heinrich (Wiedenmann, 1995), none of which has been reported from FL In E. Africa attacks other hosts of genera *Chilo* and *Sesamia* (Overholt et al., 1994, 1996). Elsewhere reported to have displaced native parasitoids, including *Apanteles diatraeae* Muesebeck (Hymenoptera: Braconidae) (Lynch and Thomas, 2000), but *A. diatraeae* does not occur in FL; indeed, an attempt to introduce it into FL in 1934 failed (Frank and McCoy, 1993). It will not successfully attack all stem-boring pyralid larvae, not least because some of these encapsulate the parasitoid (Potting et al., 1997). So far as is known, attacks only the target in FL, and even vs this, has not been very successful as a classical biocontrol agent, so augmentative releases have been made. May be considered geographically monophagous in FL unless further evidence shows otherwise.

Table 1 (*continued*)

Cryptochetum iceryae (Williston) (Diptera: Cryptochetidae) [misspelled elsewhere as *Cryptochaetum*, misidentified elsewhere as *C. monophlebi* Skuse], released in FL in 1917, from Australia (via CA), vs cottonycushion scale, *Icerya purchasi* Maskell (Homoptera: Margarodidae), a target native to Australia; was reported as established but has not been seen in recent years (Bennett, 1993). *Specificity*. Native to Australia, has successfully attacked *Icerya purchasi* in several countries around the world. In laboratory trials in Israel, it was found to develop on *I. purchasi*, but not on the congeneric *I. aegyptiaca* (Douglas) (breadfruit mealybug) (Mendel and Blumberg, 1991). May be monophagous.

Cryptognatha nodiceps Marshall (Coleoptera: Coccinellidae), released in FL in 1936, from Trinidad, vs coconut scale, *Aspidiotus destructor* Signoret (Homoptera: Diaspididae). The species has been observed in recent decades in FL (Gordon, 1985). *Specificity*. Not known to prey on other Diaspididae (Gordon, 1985) so here considered monophagous.

Cryptolaemus montrouzieri Mulsant (Coleoptera: Coccinellidae), released in FL in 1930, from Australia (via CA) vs citrus mealybug, *Planococcus citri* (Risso) (Homoptera: Pseudococcidae), a target native to Asia. *Specificity*. Elsewhere feeds on various Coccoidea (Gordon, 1985), those that exist in FL are *Coccus viridis* (Green), *Pulvinaria psidii* (Maskell) (Homoptera: Coccidae), *Dysmicoccus boninsis* (Kuwana), *D. brevipes* (Cockerell), *Ferrisia virgata* (Cockerell), *Maconellicoccus hirsutus* (Green), *Nipaecoccus nipae* (Maskell), *Planococcus citri* (Risso), *Pseudococcus comstocki* (Kuwana), *P. longispinus* (Targioni-Tozzetti), *P. maritimus* (Ehrhorn), *P. viburni* (Signoret), *Saccharicoccus sacchari* (Cockerell) (Homoptera: Pseudococcidae), *Dactylopius confusus* (Cockerell), *D. opuntiae* (Cockerell), and *D. tomentosus* (Lamarck) (Homoptera: Dactylopiidae), and *Eriococcus araucariae* (Maskell) (Homoptera: Eriococcidae). All are adventive pests in FL with the exception of *Pseudococcus maritimus*, *Dactylopius confusus*, and *D. opuntiae*, which are presumed to be native (G.S. Hodges, personal communication).

Diachasmimorpha longicaudata (Ashmead) (Hymenoptera: Braconidae) [synonym *Biosteres longicaudatus*], released in FL in 1972 from Asia (via Mexico and Hawaii), vs Caribbean fruit fly, *Anastrepha suspensa* (Loew) (Diptera: Tephritidae), a target native to the W. Indies; it is established (Baranowski et al., 1993; Ovruski et al., 2000). *Specificity*. Not monophagous, it was imported because, in the Pacific, it attacks *Bactrocera dorsalis* (Hendel), a tephritid whose larvae infest fruits.

Diaphorencyrtus aligarhensis (Shafee, Alam and Agarwal) (Hymenoptera: Encyrtidae), released in FL in 2000 from Taiwan vs citrus psyllid, *Diaphorina citri* Kuwayama (Homoptera: Psyllidae) native to Asia (Hoy and Nguyen, 2000b). *Specificity*. Imported into S. Africa, would not develop on its target *Trioza erytreae* (Del Guercio), African citrus psylla, and no hosts other than *D. citri* are known (Prinsloo, 1985).

Doryctobracon areolatus (Szépligeti) (Hymenoptera: Braconidae), released in FL in 1969 from Argentina? (via Trinidad) vs Caribbean fruit fly, *Anastrepha suspensa* (Loew) (Diptera: Tephritidae), target native to the W. Indies, established (Baranowski et al., 1993; Ovruski et al., 2000). *Specificity*. Not monophagous, imported because in S. America attacks tephritids whose larvae infest fruits (Ovruski et al., 2000).

Encarsia lahorensis (Howard) (Hymenoptera: Aphelinidae) was released in FL in 1977, from Pakistan vs citrus whitefly, *Dialeurodes citri* (Ashmead) (Homoptera: Aleyrodidae), a target native to Asia. *Specificity*. In FL, it is often reared from *D. citri*, sometimes from *D. kirkaldyi* (Kotinsky) and *Singhiella citrifolii* (Morgan), and rarely from *Aleurodicus dispersus* Russell. All of these hosts are Aleyrodidae, and probably all are of Asian origin (G.A. Evans, personal communication).

Encarsia perplexa Huang and Polaszek (Hymenoptera: Aphelinidae), released in FL in 1976, from India (via Mexico and TX) vs citrus blackfly, *Aleurocanthus woglumi* Ashby (Homoptera: Aleyrodidae), a target native to Asia. Was misidentified at the time as *Encarsia opulenta* (Silvestri) (Huang and Polaszek, 1998). *Specificity*. In FL, is often reared from *A. woglumi*, rarely from *Aleurothrixus floccosus* (Maskell) a host probably of Neotropical origin (G.A. Evans, personal communication). Has been reared elsewhere from *Aleuroclava kuwani* (Takahashi), *Aleuroplatus pectiniferus* Quaintance and Baker, and *Aleurothrixus aepim* (Goeldi) (G.A. Evans, personal communication). Barring further evidence, may be considered monophagous in FL.

Encarsia sankarani Hayat (Hymenoptera: Aphelinidae), released in FL in 1976–1977, from India, vs tea scale, *Fiorinia theae* Green (Homoptera: Diaspididae), a pest of camellia, holly, and other ornamental plants, and native to Asia; however, survival during winters in northern FL was poor, and the parasitoid was not detected in the spring of 1979 (Nguyen and Bennett, 1994). Release of the wasp in central FL might be worthwhile, in hope that it may become established there and migrate northward in spring each year. *Specificity*. Is not reported from any host other than *F. theae* (G.A. Evans, personal communication) so should be considered monophagous.

Encarsia smithi (Silvestri) (Hymenoptera: Aphelinidae), released in FL in 1979 in some localities, together with *Encarsia perplexa* (see above) or *Amitus hesperidum* (see above), when these were being released vs *Aleurocanthus woglumi*; male larvae of *E. smithi* are facultative adelphoparasitoids of *Encarsia* spp., so release of *E. smithi* was partially detrimental to the control of *A. woglumi* (Nguyen et al., 1983; Thompson et al., 1987). Target is native to Asia. However, *E. smithi* not detected in FL in recent years (G.A. Evans, personal communication). *Specificity*. In FL, reported from the non-native host *Bemisia tabaci* (Gennadius), but this record probably erroneous (G.A. Evans, personal communication). Elsewhere reported from *Aleurocanthus citriperdus* Quaintance and Baker, *A. inceratus* Silvestri, and *Aleurocanthus spiniferus* (Quaintance) (G.A. Evans, personal communication). All new host records reported from China are from *A. spiniferus* (Huang and Polaszek, 1998), so perhaps spiny whitefly is the normal host and reason for lack of evident populations in FL is because of absence of this normal host (G.A. Evans, personal communication). No evidence of its attack on native whiteflies in FL.

Encarsiella noyesi Hayat (Hymenoptera: Aphelinidae), released in FL in 1998, from Trinidad and Tobago) (via CA) vs giant whitefly, *Aleurodicus dugesii* Cockerell, a pest of Mexican origin (Nguyen and Hamon, 2002). *Specificity*. Is not monophagous, attacks other whiteflies of genera *Aleurodicus* and *Aleurothrixus* (Polaszek and Hayat, 1992; Kairo et al., 2001). However, all representatives of these genera in FL are adventive pests (G.S. Hodges, personal communication).

Entedononecremnus krauteri Zolnerowich and Rose (Hymenoptera: Eulophidae), released in FL in 1997, from TX (via CA) vs giant whitefly, *Aleurodicus dugesii* Cockerell, a pest of Mexican origin (Nguyen and Hamon, 2002). *Specificity*. So far as is known, it is monophagous (Zolnerowich and Rose, 1996).

Euplectrus puttleri Gordh (Hymenoptera: Eulophidae) was released in FL in 1981, from Brazil, vs velvetbean caterpillar, *Anticarsia gemmatalis* Hübner (Lepidoptera: Noctuidae), a target which is native to the W. Indies and other parts of tropical America. *Specificity*. Host trials showed that the parasitoid is essentially monophagous, with rare development in one non-congeneric noctuid larva (Puttler et al., 1980).

(*continued on next page*)

Table 1 (*continued*)

Goetheana shakespearei Girault (Hymenoptera: Eulophidae) [synonym *Dasyscapus parvipennis* Gahan], released in FL in 1986 in a greenhouse, from Africa (via CA), vs redbanded thrips, *Selenothrips rubricinctus* (Giard), a target native to Asia. It was detected in a greenhouse in 1992 in the same county but not close to the release site, so the means of arrival and establishment are uncertain (Bennett et al., 1993). *Specificity*. Outside FL, this wasp attacks several thrips genera (*Selenothrips, Heliothrips, Caliothrips*) of the subfamily Panchaetothripinae of the family Thripidae (Loomans and Van Lenteren, 1995). It has not been reported to attack native FL thrips, but this might yet happen.

Gratiana boliviana Spaeth (Coleoptera: Chrysomelidae), from Argentina, was released in 2003 vs *Solanum viarum* Dunal (Medal et al., 2003a,b). In 2004, progeny of released specimens were found at the field sites, evidence of establishment. *Specificity*. Non-target testing showed it is monophagous (Medal et al., 2002).

Gyranusoidea indica Shafee, Alam and Agarwal (Hymenoptera: Encyrtidae), released in FL in 2002; native to India, it was re-exported, from Egypt (via Puerto Rico) vs pink hibiscus mealybug, *Maconellicoccus hirsutus* (Green) (Homoptera: Pseudococcidae) (Michaud and Evans, 2000). Target is native to Asia. *Specificity*. Is also known from an unidentified sp. of *Nippaecoccus* and from *Nipaecoccus viridis* (Newstead) in Asia (Noyes and Hayat, 1994). Thus, it attacks members of more than one genus of Pseudococcidae. However, in FL it is monophagous so far as is known. Even if it should be found in FL to attack *Nippaecoccus*, all spp. of that genus are adventive pests.

Hambletonia pseudococcina Compere (Hymenoptera: Encyrtidae), released in FL in 1944, from S. America (via Puerto Rico) vs pineapple mealybug, *Dysmicoccus brevipes* (Cockerell) (Homoptera: Pseudococcidae). Target is native to the Neotropical region, and was first detected in FL in 1880 (Miller et al., 2002). *Specificity*. In Africa, the parasitoid attacks *Planococcoides njalensis* (Laing), which does not occur in FL, but the only other known host is *Dysmicoccus brevipes* (Noyes and Hayat, 1994), so we consider it monophagous in FL.

Harmonia dimidiata (F.) (Coleoptera: Coccinellidae), released in FL in 1925, from China (via CA) vs spirea aphid, *Aphis spiraecola* Patch (Homoptera: Aphididae), a target native to Asia. The presence of this species in the USA may not have resulted from biocontrol introductions, but from immigration (Gordon, 1985) but we include it here because attempts were made to introduce it. It has been reported from several counties in the FL peninsula (Peck and Thomas, 1998). *Specificity*. Gordon (1985) listed known prey of the genus *Harmonia*, but not specifically the prey of *H. dimidiata*: members of this genus prey on numerous aphid species and to a lesser extent on other Homoptera (Coccidae, Dactylopiidae, Diaspididae, Margarodidae, and Psyllidae) (Gordon, 1985). A prey list for *H. dimidiata* is needed.

Hydrellia pakistanae Deonier (Diptera: Ephydridae), released in FL in 1987, from India, Pakistan and China vs hydrilla, *Hydrilla verticillata* (Lf.) Royle (Hydrocharitales: Hydrocharitaceae), a weed native to Eurasia, and became established (Buckingham, 1994). *Specificity*. Tests were conducted with 51 plant spp. in 27 families, revealing a high level of specificity in feeding trials, although there was some feeding on plants in Hydrocharitaceae, Najadaceae, and Potomogetonaceae (Buckingham et al., 1989).

Larra bicolor F. (Hymenoptera: Sphecidae), released in FL in 1981 from Brazil (via Puerto Rico) vs *Scapteriscus* mole crickets (Orthoptera: Gryllotalpidae); became established in a small part of Broward County only and performed poorly; subsequent releases of stock from Bolivia in 1988/1989 in Alachua County led to establishment (Frank et al., 1995) with subsequent spread in northern FL The 3 spp. of *Scapteriscus* that occur in FL are native to southern S. America. *Specificity*. Is not a risk to the native mole crickets in the USA, which are taxonomically and physiologically distinct at least at the level of tribe and one of them has its own native sp. of *Larra* (Frank, 1998).

Leptomastidea abnormis (Girault) (Hymenoptera: Encyrtidae) [synonym *Leptomastix abnormis*], released in 1917, from Italy (via CA) vs citrus mealybug, *Planococcus citri* (Risso) (Homoptera: Pseudococcidae), a target native to Asia. *Specificity*. Was also imported into CA where, in a survey of its effects on non-target hosts, it was found to attack only one of three other species of *Planococcus* co-occurring on citrus; that one was *P. gahani* Green, which likewise is an adventive pest, and it was only attacked at a low level (Bartlett and Lloyd, 1958). Although *P. citri* seems to be the main host, other mealybugs of the genera *Dysmicoccus*, *Ferrisia*, *Phenacoccus*, *Planococcoides*, *Planococcus*, *Pseudococcus*, *and Saccharicoccus* are reported as hosts from various places around the world, but not in FL (Noyes and Hayat, 1994).

Leptomastix dactylopii Howard (Hymenoptera: Encyrtidae), was released in 1940, from the Neotropics (via CA) vs citrus mealybug, *Planococcus citri* (Risso) (Homoptera: Pseudococcidae), but may already have occurred in FL before this importation; the target is native to Asia. *Specificity*. In a survey of its effects on non-target hosts in CA, it was found to attack none of three other species of *Planococcus* co-occurring on citrus, only the target (Bartlett and Lloyd, 1958). Nevertheless, although *P. citri* seems to be the main host, other mealybugs of the genera *Dysmicoccus*, *Ferrisia*, *Phenacoccus*, *Planococcoides*, *Planococcus*, and *Pseudococcus*, seem to be reported as hosts from various places around the world, although not in FL (Noyes and Hayat, 1994).

Lipolexis oregmae (Gahan) (Hymenoptera: Aphidiidae) [synonym *L. scutellaris*], released in 2000 from Guam vs brown citrus aphid, *Toxoptera citricida* (Kirkaldy) (Homoptera: Aphididae) (Hoy and Nguyen, 2000a). Seems established even if has had little effect on target. Specificity: had been reported elsewhere, before release in FL, to attack *Aphis gossypii* Glover, *A. nerii* (Boyer de Fonscolombe), *A. spiraecola* Patch, *A. craccivora* Koch, *Rhopalosiphiphum padi* (L.), and *Toxoptera aurantii* (Boyer de Fonscolombe) as well as *T. citricida*, all of which now occur in FL as adventive pests (Evans and Stange, 1997).

Neochetina bruchi Hustache (Coleoptera: Curculionidae), released in 1974, from Argentina vs waterhyacinth, *Eichhornia crassipes* (Martius) Solms (Liliales: Pontederiaceae), a weed native to S America. *Specificity*. Host-specificity trials showed that it does not complete its life cycle except on waterhyacinth (DeLoach, 1976; DeLoach and Cordo, 1976), so is monophagous, although it rarely feeds on *Reussia* (which does not occur in FL) and another species of *Eichhornia*, which is an invasive weed in FL. Further testing was done before *N. bruchi* was imported into other countries, but the conclusion about host-specificity remained the same (Julien et al., 1999).

Neochetina eichhorniae Warner (Coleoptera: Curculionidae), released in 1972 from Argentina vs waterhyacinth, *Eichhornia crassipes* (Martius) Solms (Liliales: Pontederiaceae), a weed native to S. America. *Specificity*. Feeding trials in Argentina by Perkins (1973) convinced him of the host-specificity of *N. eichhorniae*, but Center (1994) pointed out the taxonomic confusion between this species and *N. bruchi* at the time of the trials. What may be stated is that since release in FL, *N. eichhorniae* has been an effective biological control agent of *E. crassipes* (Center, 1994) without obvious non-target effects. Much further testing was done before importation of *N. eichhorniae* into other countries, but the only plant on which any larval development occurred was *Pontederia cordata* L., and no larvae completed development on this plant (Julien et al., 1999). Note that *P. cordata* is native to FL Because larvae did not complete development on *P. cordata*, we consider *N. eichhorniae* to be monophagous in FL.

Table 1 (*continued*)

Neodusmetia sangwani (Subba Rao) (Hymenoptera: Encyrtidae) [synonym *Dusmetia sangwani*], was released in FL in 1957 in small numbers and 1959 in large numbers from India vs Rhodesgrass mealybug, *Antonina graminis* (Maskell) (Homoptera: Pseudococcidae); perhaps it contributed to competitive displacement of *Anagyrus antoninae*, a parasitoid that had been released a few years earlier vs this pest (see above) (Bennett, 1994). The target is believed to be native to Asia. *Specificity*. We detected no other host records so we believe *N. sangwani* is monophagous.

Neohydronomus affinis Hustache (Coleoptera: Curculionidae) [misidentified earlier as *N. pulchellus* Hustache], released in FL in 1987–1988, from Brazil (via Australia) vs waterlettuce, *Pistia stratiotes* L. (Arales: Araceae), a weed whose origin is obscure but is doubtfully native to FL; it became established (Center, 1994). *Specificity*. Is monophagous (Thompson and Habeck, 1989)

Niphograpta albiguttalis Warren (Lepidoptera: Pyralidae) [synonym *Sameodes albiguttalis*], released in FL in 1977–1979, from Argentina, vs waterhyacinth, *Eichhornia crassipes* (Martius) Solms (Liliales: Pontederiaceae), a weed native to S America. It became established (Center, 1994). *Specificity*. This pyralid is essentially monophagous in that its larvae have occasionally been found feeding on a congener of waterhyacinth in the field in Argentina, but that species (*E. azurea* (Swartz) Kunth.) is not native to FL (Cordo and DeLoach, 1978) and is a declared weed.

Ormia depleta (Wiedemann) (Diptera: Tachinidae) [synonym *Euphasiopteryx depleta*], released in FL in 1988 vs *Scapteriscus* mole crickets (Orthoptera: Gryllotalpidae); has become established from ~28 °N southward. The three *Scapteriscus* mole crickets occurring in FL are native to southern S. America. *Specificity*. Host-finding is by phonotaxis, and the radically different songs of the native mole crickets, which are taxonomically distinct at the level of tribe, make them safe from attack (Frank, 1998).

Oxyops vitiosa Pascoe (Coleoptera: Curculionidae), released in FL in 1997 vs melaleuca, *Melaleuca quinquenervia* (Cav.) S.T. Blake (Myrtales: Myrtaceae); this weevil from Australia, has become established at several places in southern FL (Center et al., 2000). The weed, too, is native to Australia. *Specificity*. in the field in Australia, the weevil was found to attack only *Melaleuca quinquenervia*, and in laboratory trials it fed at a high level on three *Melaleuca* spp. and at a lower level on guava (*Psidium guajava*) which, although it belongs to Myrtaceae, does not support development of the weevil larvae (Balciunias et al., 1994). Thus, if guava trees should be close to melaleuca trees, they may suffer collateral damage, but infestations of melaleuca trees are mainly in the Everglades, where guava does not occur. There is no evidence that guava in dooryard plantings will suffer damage of any consequence; it is now illegal in FL to grow or possess *Melaleuca quinquenervia*, so that plant should not occur adjacent to guava. A report (Halbert, 2002) suggests it has caused collateral damage to *Callistemon* (bottlebrush trees), which were introduced to FL as ornamental plants and may not be distinct from *Melaleuca* at the generic level; despite this feeding damage, we consider *O. vitiosa* to be monophagous in FL.

Pseudacteon curvatus Borgmeier (Diptera: Phoridae), released in FL in 1999, from S. America vs red imported fire ant, *Solenopsis invicta* Buren (Hymenoptera: Formicidae), which is native to S. America. *Specificity*. Trials ranked attacks on the native *S. geminata* at 6% of those on *S. invicta*; this was deemed an acceptable risk (Porter, 2000). *P. curvatus* is not monophagous in FL, but non-target effects are minor.

Pseudacteon tricuspis Borgmeier (Diptera: Phoridae), released in FL in 1997, from S. America vs red imported fire ant, *Solenopsis invicta* Buren (Hymenoptera: Formicidae), a S American native. *Specificity*. Trials showed it is 15 × more likely to attack *S. invicta* than the native *S. geminata*; this risk was deemed acceptable (Porter and Alonso, 1999). *P. tricuspis* is not monophagous in FL, but non-target effects minor.

Pseudaphycus mundus Gahan (Hymenoptera: Encyrtidae), released in FL in 1932, from Louisiana, vs gray sugarcane mealybug, *Dysmicoccus boninsis* (Kuwana) and pink sugarcane mealybug, *Saccharicoccus sacchari* (Cockerell) (Homoptera: Pseudococcidae)—although the latter species apparently was not present in FL until 1944 (Miller et al., 2005)—and established (Frank and McCoy, 1993). The targets are native to Asia and Africa respectively. The parasitoid is believed to be native to Louisiana, not to FL. *Specificity*. Also attacks some other mealybugs of the genera *Phenacoccus*, *Planococcoides*, *Planococcus*, and *Pseudococcus* in various parts of the world (Noyes and Hayat, 1994), so is not monophagous.

Pseudectroma europaea (Mercet) (Hymenoptera: Encyrtidae) [synonym: *Timberlakea purpurea*], released in FL in 1957, with more in 1959, from France where it is a parasitoid of *Antonina purpurea* Signoret, vs Rhodesgrass mealybug, *Antonina graminis* (Maskell) (Homoptera: Pseudococcidae), became established but was not found in a survey in the late 1980s by F. D. Bennett (Bennett, 1994). However, Bennett (1994) detected the presence of another species, *Pseudectroma* sp., perhaps native to SE Asia, and for which there was no record of release in FL Thus, *P. europaea* may no longer exist in FL. The target is native to Asia. *Specificity*. *P. europaea* attacks *Antonina purpurea* in Europe, so is not monophagous. No host other than *A. graminis* is known in FL although there are three bamboo-infesting adventive species of *Antonina*, so should be considered monophagous in FL.

Quadrastichus haitiensis (Gahan) (Hymenoptera: Eulophidae) [synonym *Tetrastichus haitiensis*, see LaSalle, 1994] was released in FL in 1969, 1970, and 1971, from Puerto Rico, vs “sugarcane rootstock weevil borer” (otherwise known as Apopka weevil), *Diaprepes abbreviatus* (L.) (Coleoptera: Curculionidae). Scant evidence of establishment (Beavers et al., 1980, 1983; Hall et al., 2001). Additional material was imported from Puerto Rico in 1998, reared, and released in 1999–2002. Its permanent establishment in FL is still uncertain. The target is native to one or more W. Indian islands and was detected in 1960 as an immigrant pest in FL (Woodruff, 1968). *Specificity*. It is not monophagous because it also attacks eggs of weevil pests belonging to the genus *Exophthalmus*, which do not occur in FL (Schauff, 1987), and *Pachnaeus* (Woodruff, 1981; Hall et al., 2001) on citrus. All these weevils belong to the subfamily Entiminae and lay eggs in folded leaves on living plants.

Rodolia cardinalis (Mulsant) (Coleoptera: Coccinellidae), released in FL in 1899, from Australian (via CA) vs cottony cushion scale, *Icerya purchasi* Maskell (Homoptera: Margarodidae), a target native to Australia. Is recorded from end to end of the FL peninsula (Peck and Thomas, 1998), where it controls cottony cushion scale. *Specificity*. Prey almost restricted to monophlebine scale insects (Gordon, 1985), none of which other than cottony cushion scale is reported from FL. We consider it monophagous in FL.

Scutellista cyanea Motschulsky (Hymenoptera: Pteromalidae), released in FL in 1899, from Italy vs barnacle scale, *Ceroplastes cirripediformis* Comstock (Homoptera: Coccidae), a target native to Asia. *Specificity*. Larvae feed externally on eggs of this and other scale insects, and have been termed predators rather than parasitoids. Other scales attacked include Florida wax scale, *Ceroplastes floridensis* Comstock (which, despite its name, is probably not native to FL), *Parasaissetia nigra* (Nietner) (a black scale which is a pest of ornamental plants, and probably not native to FL), and one or more of three similar spp. of *Saissetia* (which occur on citrus and/or ornamental plants in FL, all of which are black, and none of which is clearly native to FL) (G.S. Hodges, personal communication); elsewhere, it also attacks the coccid *Lecanium corni* Bouché (which is an adventive species in FL) and the CAn native pseudococcid *Phenacoccus artemisiae* Ehrhorn. It thus is not monophagous, and feeds on at least four genera of scale insects of the family Coccidae and one of Pseudococcidae, but it is not known to attack any native species in FL.

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Table 1 (*continued*)

Steinernema scapterisci Nguyen and Smart (Rhabditida: Steinernematidae) [misidentified in earlier publications as "Uruguayan strain of *Neoaplectana carpocapsae* (Weiser)"], released in FL in 1985, from Uruguay, vs *Scapteriscus* mole crickets (Orthoptera: Gryllotalpidae); has become established at scattered localities in FL and is spreading, carried by newly-infected host mole crickets. Experimental releases in 1989–1992 and commercial sales from late 1980s through mid-1990s established it in more FL counties. Field demonstrations in 2000–2003 spread it to still more counties. It is available again as a biopesticide, and commercial sales should spread it still more widely. The three species of *Scapteriscus* present in FL are native to southern S. America. *Specificity*. Exactly why it does not reproduce in native mole crickets is unclear (although that species is distinct at the tribal level), but field evidence shows that it has not done so even in mixed populations; furthermore, the native mole cricket *Neocurtilla hexadactyla* (Perty) has its own specialized *Steinernema* species which seems not to attack *Scapteriscus* mole crickets (Frank, 1998).
Stenocranophilus quadratus Pierce (Strepsiptera: Stylopidae), released in FL in 1959, from Jamaica (via Trinidad and NJ), vs "West Indian sugarcane delphacid" (its approved Entomological Society of America "common" name, but is known in the W. Indies as canefly), *Saccharosydne saccharivora* (Westwood), which is native to the W. Indies and parts of S. America (Hall and Bennett, 1994). *Specificity*. Reported, remarkably, in Czech Republic with *Megadelphax sordidulus* (Stål) (Delphacidae) as host (Lauterer, 1996), so (if the i.d. is correct) is not monophagous and might be expected to attack *Perkinsiella saccharicida* Kirkaldy (Delphacidae), a pest of sugarcane from the Pacific which has invaded some sugarcane-growing areas in the New World. *P. saccharicida* was detected in FL in 1982 and in Venezuela in 1987, following earlier detection in Ecuador, Peru, and Colombia (Sosa, 1985; Yépez et al., 1988). Yet, neither in FL (where *S. quadratus* is introduced), nor Venezuela (where it is native), has it been reported to attack *P. saccharicida.* It was the native predator of *S. saccharivora* eggs *Tytthus parviceps* Reuter (Heteroptera: Miridae) that in Ecuador adapted to *P. saccharicida* after the latter's invasion (Fernández and Escobar, 2000), and in Colombia it was the native parasitoid *Anagrus* sp. (Hymenoptera: Myrmaridae) of *S. saccharivora* eggs that adapted. Nowhere has *S. quadratus* been reported to attack the invading *P. saccharicida* although this latter is a close relative of the natural host *S. saccharivora* and occurs on the same host plant. Therefore, we question Lauterer's (1996) report, and we consider *S. quadratus* to be monophagous in FL, although further investigation is needed.
Tamarixia radiata (Waterston) (Hymenoptera: Eulophidae), released in FL in 1999 (from Taiwan and Vietnam) vs citrus psyllid, *Diaphorina citri* Kuwayama (Homoptera: Psyllidae), which is native to Asia. *Specificity*. Believed to be monophagous (Hoy and Nguyen, 2000b).

Note. Postal abbreviations for names of states: CA (California), FL (Florida), GA (Georgia), MS (Mississippi), TX (Texas) etc. are used to save space.

A further 35 species were excluded from Table 1 but are documented, together with reasons for exclusion, in Table 2.

Of the 32+ targeted insect pests, 12 were pests of citrus, six of other fruits and ornamentals, five of sugarcane, and two of grasses other than sugarcane; of the six targeted weeds, five were aquatic (Table 3).

3.2. What is the host range of released natural enemies?

Of the 60 established classical biological control agents, 24 have native Florida species in their known potential host ranges (Tables 1 and 4). Of these 24 agents, 19 have relatively broad potential host ranges (i.e., 16 are hemi-polyphagous and three are polyphagous; see footnote of Table 4 for explanation), and five have relatively narrow potential host ranges. Of the first 19 agents, 14 are hymenopterans [Aphelinidae (6), Aphidiidae (1), Braconidae (2), Encyrtidae (3), and Eulophidae (2)] and five are coleopterans (Coccinellidae), and of the other five agents, three are hymenopterans [Encyrtidae (1) and Eulophidae (2)] and two are dipterans [Phoridae (2)]. Among the polyphagous agents, *Cirrospilus ingenuus* (Eulophidae) may have an exceptionally broad host range, including Agromyzidae (Diptera), Curculionidae (Coleoptera), Lyonetiidae (Lepidoptera), and Encyrtidae (Hymenoptera), and must, therefore, stand as the most threatening of all established biological control agents in Florida to non-target species. Behavioral and taxonomic studies to compare specimens from different locations are warranted, however, because it seems remarkable that a single species should have so diverse an array of hosts (see Askew, 1971).

Simply tabulating the host ranges of biological control agents ignores the chronological sequence of introduction. If the risk of future non-target effects of classical biological control introductions is to be estimated from the history of previous introductions, then historical trends must be part of the equation (see Henneman and Memmott, 2001). Although we have deferred consideration of introduced species that did not establish on the target, several such species within three families of coleopterans, Carabidae, Coccinellidae, and Curculionidae, that have been noted to contain broadly generalist species and/or species with demonstrated non-target effects, make the point particularly well.

Among the Carabidae, two species of one genus, *Calosoma*, were released in Florida in unsuccessful biological control programs several times before 1950, despite the fact that three *Calosoma* spp. are native to Florida (Frank and McCoy, 1993). Adults of *Calosoma* spp., which are relatively large, probably drew attention to themselves as potential biological control agents in the early decades of the gypsy moth campaign, when they were seen attacking gypsy moth larvae in daylight. The two introduced species are not specialists, but might turn their attention to almost any abundant caterpillars, but they never became established, most likely because of climatic mismatch. Two species of two genera, *Pheropsophus* and *Stenaptinus*, have been imported recently for biological control of *Scapteriscus* mole crickets (Frank and McCoy, 1993). As adults, these species are scavengers and generalist predators, but as larvae, they are specialist predators on mole cricket eggs. Presence of larval prey would, therefore, limit population sizes and dispersal. Nevertheless, the species have not been released because under artificial laboratory conditions, their larvae also will feed on eggs of the native non-pest mole cricket *Neocurtilla hexadactyla* (Perty).

Table 2
Species excluded from the list of established classical biological control introductions

Aphelinus spiraecolae Evans and Schauff (Hymenoptera: Aphelinidae)	Released in FL in 1995, from S. China, against spirea aphid, *Aphis spiraecola* Patch (Homoptera: Aphididae) (Yokomi and Tang, 1995; R.K. Yokomi, personal communication). The target probably is native to E Asia (S.E. Halbert, personal communication). The parasitoid has not been shown to be established in FL.
Aphytis lingnanensis Compere (Hymenoptera: Aphelinidae)	Believed to occur in FL in at least two morphologically indistinguishable "biotypes." The role of classical biological control in supplying these biotypes is not understood (Frank and McCoy, 1993; Gupta, 1994).
Aprostocetus gala (Walker) (Hymenoptera: Eulophidae) [synonym *A. vaquitarum* (Wolcott)]	Released in FL in 1999, from Guadeloupe against "sugarcane rootstock weevil borer" (otherwise known as Apopka weevil), *Diaprepes abbreviatus* (L.) (Coleoptera: Curculionidae), a target native to one or more West Indian islands. Its hosts are *Diaprepes abbreviatus* and *D. famelicus* (Olivier), the second of which does not occur in FL (Schauff, 1987). Curiously, this parasitoid also is reported from sorghum midge (*Stenodiplosis sorghicola* Coquillet [Diptera: Cecidomyiidae]) in India (Kausalya et al., 1997). It seems not to be established in FL.
Bagous affinis Hustache (Coleoptera: Curculionidae)	Released in FL in 1987, from India, against hydrilla, *Hydrilla verticillata* (Lf.) Royle (Hydrocharitales: Hydrocharitaceae), a target native to Eurasia. This weevil will feed on other species of Hydrocharitaceae (*Egerea* and *Elodea*) but seems not to have become established in the USA (Buckingham and Bennett, 1998).
Bagous hydrillae O'Brien (Coleoptera: Curculionidae)	Released in FL in 1991, from Australia, against hydrilla, *Hydrilla verticillata* (Lf.) Royle, a target native to Eurasia, but seems not to have become established in FL (Buckingham, 1994).
Bufo marinus L. (Anura: Bufonidae)	"Cane toads", native to northern S. America, were imported from Puerto Rico into FL and LA in 1934, and released in sugarcane-growing areas in attempt to control "white grubs" (larvae of pest Scarabaeidae). This action was the result of unsubstantiated claims that the toad was proving a successful biocontrol agent in Puerto Rico. Although it had been successfully established in that island in 1920, its effects had not been measured. During the following 22 years there was no evidence of the establishment of this toad in sugarcane growing areas of FL or LA, and it was thought that the individuals released in 1934 were killed by freezing temperatures in winter (Clausen, 1956). But, *B. marinus* became established in southern FL as result of accidental release of about 100 specimens from the stock of a pet dealer at Miami airport in 1955, and by subsequent releases by pet dealers in the 1960s (Krakauer, 1968).
Cactoblastis cactorum Berg (Lepidoptera: Phycitidae)	A moth of S. American origin that harms rare native *Opuntia* cacti in FL. However, it was not introduced into FL for biocontrol purposes [despite implication by Howarth (2000) that such introduction occurred]. Its most likely method of entry to FL was as a contaminant of ornamental *Opuntia*, imported by the horticulture trade, probably from the Dominican Rep. (Pemberton, 1995). Others claimed that it may have flown to FL from Cuba, although it is the arid South coast, not the humid North, of Cuba that supports most *Opuntia* populations, and although the adults do not fly strongly.
Ceranisus menes (Walker) (Hymenoptera: Eulophidae)	Released in Dade County in 1992–1993, with a uniparental strain from Japan, and a biparental strain from Thailand (Castineiras et al., 1996). The species already was present in FL, but it was hoped that one or both of the imported strains might provide improved control of melon thrips, *Thrips palmi* Karny. Confirmation of establishment of either of the imported strains is at best difficult, and seems not to have been attempted.
Ceratogramma etiennei Delvare (Hymenoptera: Trichogrammatidae)	Released in FL in 1998, from Guadeloupe against "sugarcane rootstock weevil borer" (otherwise known as Apopka weevil), *Diaprepes abbreviatus* (L.) (Coleoptera: Curculionidae), a target which is native to one or more West Indian islands (Hall et al., 2001). It seems not to be established (D.M. Amalin, personal communication).
Cichla ocellaris Bloch and Schneider and *C. temensis* Humboldt (Perciformes: Cichlidae)	Seem to have been released beginning in 1986 by the Florida Game and Fresh Water Fish Commission (now Fresh Water Fish and Wildlife Commission) to add to "sport fishing" (Courtenay, 1997). They are collectively known as "peacock bass." A second objective was "to control populations of other nonindigenous fishes" in canals in Dade County to which they would largely be restricted because of their sensitivity to low temperatures (Cox et al., 1997). These two species seem to be the closest approximation to a vertebrate predator deliberately released and established in FL. However, their release as biological control agents seems to have been pointless, and we take this claim as a "red herring" designed to cover the real reason for their release: to please the "sport-fishing" community.
Compsilura concinnata (Meigen) (Diptera: Tachinidae)	From Europe, was released in the northeastern USA against gypsy moth (Elkinton and Boettner, 2004). Hundreds of individuals from the northeast were released in FL in 1915–1916, but the species did not become established in FL (Dowden, 1962; Frank and McCoy, 1993). It still seems not to occur in FL (G.R. Steck, personal communication). In their Table 6, Stiling and Simberloff (2000) state that it was reported by Hawkins and Marino (1997) to attack non-target species in FL; however, the latter authors made no such statement.
Cotesia plutellae Kurdjumov (Hymenoptera: Braconidae)	Introduced into various states of the USA, but has not become established, apparently because it does not survive winters there. Even in FL (N and S), where it was first released in 1990, its use as a biocontrol agent of diamondback moth, *Yponomeuta xylostella* (L.) (Lepidoptera: Yponomeutidae) is therefore limited to annual inoculative release (Frank and McCoy, 1993).
Ctenopharyngodon idella (Valenciennes) (Cypriniformes: Cyprinidae)	Known as grass carp or white amur, from China, was released in canals in FL to control aquatic weeds, from the late1970s; however, only sterile, triploid individuals were released (Cox et al., 1997), so this fish does not meet our definition of classical biological control.

(*continued on next page*)

Table 2 (*continued*)

Curinus coeruleus Mulsant (Coleoptera: Coccinellidae)	Was not known to occur in the continental U.S.A. by the early 1980s (implicit in Gordon, 1985). The conspicuous, metallic blue adults were first detected in FL in the late 1990s, suggesting arrival in that decade (M.C. Thomas, personal communication). It seems not to have been released anywhere in the continental U.S.A. (R.D. Gordon, personal communication), although it was released in Hawaii (from Mexico) in 1922. A statement in a document on Coccinellidae in FL citrus groves (Michaud et al., 2002) that *C. curinus* was "introduced in the 1950s" is misleading.
Cybocephalus binotatus Grouvelle (Coleoptera: Nitidulidae)	Stated to have been released in FL in 1997 from Thailand as a biocontrol agent for cycad scale, *Aulacaspis yasumatsui* Takagi (Homoptera: Diaspididae), a target native to Asia (Howard and Weissling, 1999; H.B. Glenn, personal communication). This predator also attacks the confamilial white mango scale, *Aulacaspis tubercularis* Newstead and lesser snow scale, *Pinnaspis strachani* (Cooley), both of which have been detected as adventive pests in FL and are of Asian origin. However, in reality the specimens released belonged to *C. nipponicus* Endrödy-Younga, which was already present in FL as an immigrant, with specimens collected as early as 1990 (Smith and Cave, 2006).
Delphastus catalinae (Horn) (Coleoptera: Coccinellidae)	Supposedly was imported into FL in 1916 and 1917 from California, with some individuals released against citrus whitefly, *Dialeurodes citri* (Ashmead) (Homoptera: Aleyrodidae). We suspected a taxonomic confusion with the native *D. pusillus* (LeConte) (Frank and McCoy, 1993). The confusion was resolved by Gordon (1994), and discussed by Hoelmer and Pickett (2003), who found no confirmation of establishment of the 1916–1917 introductions of this species in FL, although it is now present (method of arrival unknown).
Diachasmimorpha tryoni (Cameron) (Hymenoptera: Braconidae) [synonym *Opius tryoni*]	Released in FL in 1982-1987, from Australia (via Hawaii), against Caribbean fruit fly, *Anastrepha suspensa* (Loew) (Diptera: Tephritidae), a target native to the West Indies, but there is no evidence that it became established (Baranowski et al., 1993; Ovruski et al., 2000).
Encarsia opulenta (Silvestri) (Hymenoptera: Aphelinidae)	Supposedly was imported into FL in 1976 (and into Mexico and TX) as a biocontrol agent against citrus blackfly, *Aleurocanthus woglumi* (Ashby) and was instrumental in bringing about control of that pest. However, it was later discovered that the parasitoid that was imported and achieved biocontrol was *Encarsia perplexa* (Huang and Polaszek, 1998).
Euoniticellus intermedius (Reiche) (Coleoptera: Scarabaeidae)	From Africa, was released in GA in 1978–1979 in attempt to reduce cattle dung and thus help to control horn fly, *Haematobia irritans* (L.), populations. In 2001–2002 it was detected in FL (Almquist, 2002).
Gambusia affinis (Baird and Girard) (Cyprinodontiformes: Poeciliidae)	Does not fit the concept of classical biological control in FL, but we include it in order to answer stray questions. It was employed, beginning decades ago, by mosquito control agencies in FL. They reasoned that the fish eats mosquito larvae and, because it is native to FL, may be redistributed from pools where it is present to pools where it seems to be absent (having perhaps died out in shallow, saline pools during drought) to result in increased control of mosquito populations. This redistribution was carried out in FL as an environmentally sound method of controlling mosquitoes, sounder than (for example) spraying saltmarshes with diesel fuel, which was the usual method of the time. Unfortunately for the best intentions of mosquito control agencies, they were blamed for environmental harm—mixing fish populations. Fish biologists had already recognized that eastern seaboard *G. affinis* differ slightly from Gulf States *G. affinis*. The eastern seaboard populations were named *Gambusia affinis holbrooki* Girard, whereas the Gulf States populations were named *Gambusia affinis affinis* (Baird and Girard). In 1988, the two segregates were distinguished as separate species: in the east (including FL), *G. holbrooki* Girard, and in the west, *G. affinis* (Baird and Girard) (Nico and Fuller, 2001). As a result, it seemed that mosquito control agencies in FL, who thought they were redistributing *G. affinis* (e.g., Webber, 1982) found that they should have been redistributing *G. holbrooki* but may inadvertently have been distributing *G. affinis* to territory that it did not formerly occupy. There is no compelling reason why the redistribution should not continue provided that mosquito control personnel obtain stock of what is now called *G. holbrooki*. However, evidence of a beneficial effect is scarce, and other native fish species may be more effective in mosquito control in saline pools (e.g., Webber, 1982; Ritchie, 1992).
Harmonia axyridis Pallas (Coleoptera: Coccinellidae)	Has been castigated in the USA as a biocontrol introduction (from Asia) that went wrong because it may have led to the decline of some native ladybird populations through competition, and also because it enters some loosely-constructed houses late each year, apparently in attempt to hibernate, and causes a "pest problem." However, *H. axyridis* was not imported into FL—its presence here results from its immigration from neighboring states, most probably GA, where it was released; it was first noted to be established in LA (Chapin and Brou, 1991).
Horismenus elineatus Schauff (Hymenoptera: Eulophidae) (see Schauff, 1989)	Released in FL in 1991 against lesser cornstalk borer, *Elasmopalpus lignosellus* (Zeller) (Lepidoptera: Pyralidae), a pest of sugarcane and corn, but seems not to have become established (Hall, 1993; D.G. Hall, personal communication).
Hydrellia balciunasi Bock (Diptera: Ephydridae)	Released in FL and elsewhere in 1989, from Australia against hydrilla, *Hydrilla verticillata* (Lf.) Royle (Hydrocharitales: Hydrocharitaceae), a weed native to Eurasia, but seems not to have become established in FL (Grodowitz et al., 1997; G.R. Buckingham, personal communication).
Lysiphlebia japonica Ashmead (Hymenoptera: Braconidae)	Introduced into FL from Japan in 1996 against *Toxoptera citricida* (Kirkaldy) (Hymenoptera: Braconidae) but has not become established (Evans and Stange, 1997).
Microcharops anticarsiae Gupta (Hymenoptera: Ichneumonidae)	Released in FL in 1982–1983 from Costa Rica against velvetbean caterpillar, *Anticarsia gemmatalis* Hübner (Lepidoptera: Noctuidae), but is not known to be established (Gupta, 1987, 1994).

Table 2 (*continued*)

Pediobius foveolatus (Crawford) (Hymenoptera: Eulophidae)	Released in northern FL in 1975 as a biological control agent for Mexican bean beetle. Nong and Bennett (1994) state that it does not overwinter in FL, implying that it cannot have become established. It is hard to believe that it could not overwinter in southern FL or even coastal areas of central FL and spread its range northward in spring. Ability to migrate northward is evident because Nong and Bennett (1994) mention it having once been found in GA, 400 mi. N of the nearest release site in FL. If Mexican bean beetle's range does not extend to central FL, perhaps there is no opportunity for the parasitoid to overwinter and migrate northward in spring. However, Nong and Bennett (1994) state that the beetle had been spreading southward in FL and was by 1982 in Citrus, Sumter, Hernando, Pasco, and Hillsborough counties in central FL. Furthermore, Peck and Thomas (1998) record the beetle from Dade and Monroe counties, the southernmost counties in FL. The presence of *P. foveolatus* in Florida needs checking. If it is no longer present, there is reason to reintroduce it in southern FL.
Phytoseiulus persimilis Athias-Henriot (Acari: Phytoseiidae)	Native to Chile, is a predator of tetranychid mites. It has been imported and released in FL many times, targeted especially to twospotted spider mite, *Tetranychus urticae* Koch (Acari: Tetranychidae). It is now produced in U.S. commercial insectaries for sale. Although by now, probably many millions of individuals have been released, this has been done in recent years as an annual inoculative release (otherwise known as seasonal release), in which living predatory mites are released early in the growth of a crop to control pest mites, and are expected to increase in numbers during the crop's development, control the pest mites, and then die out. For example, the predatory mites, released during the winter, control twospotted mites in a strawberry crop, reproduce for a few generations, and then disappear at about the time the crop is harvested in May. The conventional explanation for disappearance is that these mites cannot survive the high temperature and humidity of FL summers. Some other phytoseiid mite species, imported either as classical biological control agents (e.g., *Typhlodromus rickeri* Chant, from India, imported in 1962, but not established) or for annual inoculative release (e.g., *Neoseiulus californicus* (Mcgregor) see Frank and McCoy, 1994) although less persistently than *P. persimilis*, have also failed to establish populations in FL as far as is known. Persistent commercial importations might by chance lead to introduction of a few individuals more resistant to high heat and humidity, which might act as founders for a permanent FL population. But this would not be classical biological control.
Platystasius asinus Loiacono (Hymenoptera: Platygastridae)	Released in 1991 from Chile against "sugarcane rootstock weevil borer" (otherwise known as Apopka weevil), *Diaprepes abbreviatus* (L.) (Coleoptera: Curculionidae) (Frank and McCoy, 1993), but has not been reported from FL subsequently, so probably is not established.
Pseudectroma sp. (Hymenoptera: Encyrtidae)	Is probably native to SE Asia, was detected in FL as a parasitoid of Rhodesgrass mealybug but had not been released in FL as a biocontrol agent and its means of arrival is unclear (contrast with *P. europaea* which was imported and released) (Bennett, 1994).
Psyllaephagus bliteus Riek (Hymenoptera: Encyrtidae)	From Australia (via California), was released in 2002 against *Glycaspis brimblecombei* Moore, red gum lerp psyllid (Homoptera: Psyllidae), a pest from Australia, but is not yet known to be established (R. Nguyen, personal communication).
Psyttalia concolor Szépligeti (Hymenoptera: Braconidae)	Released in FL in 1978, from Réunion (via France and Delaware) against Caribbean fruit fly, *Anastrepha suspensa* (Loew) (Diptera: Tephritidae), which is native to the West Indies, but there is no evidence of establishment in FL (Baranowski et al., 1993; Ovruski et al., 2000).
Rumina decollata (L.) (Pulmonata: Subulinidae)	A Mediterranean snail with predatory habits, exists in FL in a few, scattered localities, and the means of arrival is unclear (Auffenberg and Stange, 1986). It was not imported into FL as a classical biological control agent. Strangely, commercial importers were permitted (by the Florida Department of Agriculture and Consumer Services, Division of Plant Industry, to import it as a predator of brown garden snail, *Helix aspersa* Müller (Pulmonata: Helicidae), although that pest is not now known from FL (Frank and McCoy, 1994).
Thelohania solenopsae Knell, Allen and Hazard (Microsporida: Thelohaniidae)	A South American pathogen of *Solenopsis* fire ants, but was detected as an adventive species in FL, MS, and TX on *S. invicta.* It was then distributed from USA stock to additional localities. Its host range in S America is discussed by Briano et al. (2002).
Trichogramma pretiosum Riley (Hymenoptera: Trichogrammatidae)	Native to the USA, with type locality in AL. Probably includes at least part of FL in its native range, although there seem to be no museum specimens from FL collected before the 1970s to prove this. That situation is not unusual for the FL insect fauna, which still is incompletely known. Importation of living *T. pretiosum* into FL as an augmentative biological control agent beginning in the 1970s (e.g., Martin et al., 1976) is unlikely to have had any effect on the species composition of the state. One of us (JHF) discussed this in June 2002 by e-mail with John D. Pinto (University of California, Riverside), author of a 1999 revision of *Trichogramma*; he said that if he had to guess, he would guess that *T. pretiosum* is native to FL.
Wollastoniella rotunda Yasunaga and Miyamoto (Hemiptera: Anthocoridae)	Imported from Thailand and released in FL in 1995 against *Thrips palmi* Karny (Thysanoptera: Thripidae); there is no evidence that it has become established (H.B. Glenn, personal communication).

Among the Coccinellidae, the so-called "infatuation with ladybird beetles" that began at the end of the 19th century (Caltagirone and Doutt, 1989, pp. 9–10; also see Lounsbury, 1940) caused a large number of species to have been released or considered for release in Florida and elsewhere in the USA. After the success of *Rodolia cardinalis* in California, "enthusiasm for biological control was unrestrained among orchardists, self-trained entomologists, and horticultural officials in California." "From late 1891 to the middle of 1892 Koebele sent to California from Australia,

Table 3
Targets of the 60 established classical biological control agents include 38+ species, documented here.

Pest (including weeds)	Origin	Commodity	Agents(s)
Aleurocanthus woglumi Ashby (Homoptera: Aleyrodidae), citrus blackfly	Asia	Citrus	*Amitus hesperidum*, *Encarsia perplexa*, *Encarsia smithi*
Aleurodicus dugesii Cockerell (Homoptera: Aleyrodidae), giant whitefly	Mexico	Ornamentals	*Encarsiella noyesi*, *Entedononecremnus krauteri*
Alternanthera philoxeroides (Martius) Grisebach (Caryophyllales: Amaranthaceae), alligatorweed	South America	Waterways	*Agasicles hygrophila*, *Amynothrips andersoni*, *Arcola malloi*
Anastrepha suspensa (Loew) (Diptera: Tephritidae), Caribbean fruit fly	West Indies	Fruits	*Aceratoneuromyia indica*, *Aganaspis daci*, *Diachasmimorpha longicaudata*, *Doryctobracon areolatus*
Anticarsia gemmatalis Hübner (Lepidoptera: Noctuidae), velvetbean caterpillar	American tropics	Soybean	*Euplectrus puttleri*
Antonina graminis Maskell (Homoptera: Pseudococcidae), Rhodesgrass mealybug	Asia	Grasses	*Anagyrus antoninae*, *Neodusmetia sangwani*, *Pseudectroma europaea.*
Aphis gossypii Glover (Homoptera: Aphididae), melon or cotton aphid	Palearctic[a]	Cucurbits, cotton	*Aphelinus gossypii*
Aphis spiraecola Patch (Homoptera: Aphididae), spirea (or spiraea) aphid	Asia	Citrus, fruits, ornamentals	*Harmonia dimidiata*
Aspidiotus destructor Signoret (Homoptera: Diaspididae), coconut scale	Asia	Coconut	*Cryptognatha nodiceps*
Aulacaspis yasumatsui Takagi (Homoptera: Diaspididae), cycad aulacaspis scale	Asia	Cycads	*Coccobius fulvus*
Ceroplastes cirripediformis Comstock (Homoptera: Coccidae), barnacle scale	Asia	Citrus	*Scutellista cyanea*
Chrysomphalus aonidum (L.) (Homoptera: Diaspididae), Florida red scale	Asia	Citrus	*Aphytis holoxanthus*
Dialeurodes citri Ashmead (Homoptera: Aleyrodidae), citrus whitefly	Asia	Citrus	*Encarsia lahorensis*
Diaphorina citri Kuwayama (Homoptera: Psyllidae), citrus psyllid	Asia	Citrus	*Diaphorencyrtus aligarhensis*, *Tamarixia radiata*
Diaprepes abbreviatus (L.) (Coleoptera: Curculionidae), sugarcane rootstock weevil borer, or Apopka weevil	West Indies	Citrus, ornamentals	*Quadrastichus haitiensis*
Diatraea saccharalis (F.) (Lepidoptera: Pyralidae), sugarcane borer	American tropics	Sugarcane	*Alabagrus stigma*, *Cotesia flavipes*
Dysmicoccus boninsis (Kuwana) (Homoptera: Pseudococcidae), gray sugarcane mealybug	Asia	Sugarcane	*Pseudaphycus mundus*
Dysmicoccus brevipes (Cockerell) (Homoptera: Pseudococcidae), pineapple mealybug	South America[b]	Pineapple	*Hambletonia pseudococcina*
Eichhornia crassipes (Martius) Solms (Liliales: Pontederiaceae), waterhyacinth	South America	Waterways	*Neochetina bruchi*, *Neochetina eichhorniae*, *Niphograpta albiguttalis*
Fiorinia theae Green (Homoptera: Diaspididae), tea scale	Asia	Camellia, some ornamentals	*Encarsia sankarani*
Hydrilla verticillata (Lf.) Royle (Hydrocharitales: Hydrocharitaceae), hydrilla	Eurasia	Waterways	*Hydrellia pakistanae.*
Icerya purchasi Maskell (Homoptera: Margarodidae), cottonycushion scale	Australia	Citrus, some ornamentals	*Cryptochetum iceryae*, *Rodolia cardinalis*
Maconellicoccus hirsutus (Green) (Homoptera: Pseudococcidae), pink hibiscus mealybug	Asia	Hibiscus and other ornamentals	*Anagyrus kamali*, *Gyranusoidea indica*
Melaleuca quinquenervia (Cavanilles) S.T. Blake (Myrtales: Myrtaceae), melaleuca	Australia	Natural lands	*Boreioglycaspis melaleucae*, *Oxyops vitiosa*
Phyllocnistis citrella Stainton (Lepidoptera: Gracillariidae), citrus leafminer	Asia	Citrus	*Ageniaspis citricola*, *Cirrospilus ingenuus*
Pistia stratiotes L. (Arales: Araceae), waterlettuce	Africa or South America[c]	Waterways	*Neohydronomus affinis*
Planococcus citri (Risso) (Homoptera: Pseudococcidae), citrus mealybug	Asia	Citrus	*Cryptolaemus montrouzieri*, *Leptomastidea abnormis*, *Leptomastix dactylopii*
Pseudaulacaspis cockerelli (Cooley) (Homoptera: Diaspididae), false oleander scale	Asia	Oleander, mango, magnolia, dogwood	*Aphytis sankarani*
Saccharicoccus sacchari (Cockerell) (Homoptera: Pseudococcidae), pink sugarcane mealybug	Africa	Sugarcane	*Pseudaphycus mundus*
Saccharosydne saccharicida (Westwood) (Homoptera: Delphacidae), West Indian sugarcane delphacid	West Indies	Sugarcane	*Stenocranophilus quadratus*

Table 3 (*continued*)

Pest (including weeds)	Origin	Commodity	Agents(s)
Scapteriscus spp. (Orthoptera: Gryllotalpidae), tawny, southern, and shortwinged mole crickets	South America	Grasses, vegetables	*Larra bicolor*, *Ormia depleta*, *Steinernema scapterisci*
Selenothrips rubricinctus (Giard) (Thysanoptera: Thripidae), redbanded thrips	Asia or Africa	tropical fruits, ornamentals	*Goetheana shakespearei*
Sipha flava (Forbes) (Homoptera: Aphididae), yellow sugarcane aphid	eastern North America, American tropics[d]	Sugarcane	*Coelophora inaequalis*
Solanum viarum Dunal (Solanales: Solanaceae) tropical soda apple	South America	pastures, disturbed areas	*Gratiana boliviana*
Solenopsis invicta Buren (Hymenoptera: Formicidae), red imported fire ant	South America	Humans, farm animals, wildlife	*Pseudacteon curvatus*, *P. tricuspis*
Toxoptera citricida (Kirkaldy) (Homoptera: Aphididae), brown citrus aphid	Asia	Citrus	*Lipolexis oregmae*
Unaspis citri (Comstock) (Homoptera: Diaspididae), citrus snow scale	Asia	Citrus	*Chilocorus circumdatus*
Various pest aphids (Homoptera: Aphididae).	Various	Various	*Coccinella septempunctata*

[a] According to Starý (1957).
[b] According to Carter (1935) and Miller et al. (2002), but not to Ferris (1950).
[c] According to Center (1994).
[d] Florida is here assumed to be part of its native range; it is assumed to have adapted to sugarcane from wild grasses.

New Zealand, New Caledonia, and Fiji some 40,000 specimens of coccinellids comprising some 40 species. These were introduced against scale and mealybugs on citrus." Increases in introductions in Florida, however, cannot be detected until the 1930s and 1950s (Fig. 1). Of the species imported in the 1950s, only one, *Coccinella septempunctata*, became established, while several others, *Brumoides suturalis* (F.), *Catana* sp. (probably *Catana parcesetosa* (Sicard)), *Hippodamia variegata* (Goeze), *Menochilus sexmaculatus* (F.), and *Scymnus nubilis* Mulsant (F.), show no evidence of establishment (Gordon, 1985; Frank and McCoy, 1993). In total, 22 species of Coccinellidae in 19 genera were released in Florida between 1893 and 1996, but four of these species were native and only seven of them became established (Frank and McCoy, 1993, 1994). The most recent release was of *Chilocorus circumdatus.* This species proved to be useful in controlling *Unaspis citri* in Australia (Smith et al., 1995), and was introduced to Florida from there. The species has been recorded to feed on nine species of Diaspididae and two species of Coccidae (Thompson and Simmonds, 1965; Houston, 1991; Chen, 1998; Astridge, 2003), seven of which are adventive in Florida. None of the known prey records is of a scale native to Florida, but native diaspidids and coccids occur in Florida.

Among the Curculionidae, relatively many potential classical biological control agents have been considered for release in Florida (Frank and McCoy, 1993). In fact, only seven species in five genera actually were released in Florida between 1972 and 1997. The history of importation of species of Curculionidae into Florida is illustrated in Fig. 1. Two additional species, *Cyrtobagous salviniae* Calder and Sands, and *Anthonomus tenebrosus* Boheman, have been imported recently, but not yet released, against *Salvinia molesta* D.S. Mitch. (Salviniaceae) and *Solanum viarum* Dunal (Solanaceae), respectively. The first species already had immigrated to Florida and has been feeding on the related non-native plant *S. minima* Baker (Jacono et al., 2001), although the immigrant stock appears to differ genetically from the imported stock.

Importations of species within these three families of Coleoptera suggest a more careful consideration of risk of non-target effects over time. Broadly generalist species of carabids were released in the first half of the twentieth century, but not since then. The number of released species of coccinellids relative to the number of imported species was higher before the 1970s–1980s than in the 1970s–1980s and later. Importations of curculionids all occurred in 1970 or later, and the number of released species relative to the number of imported species again was relatively low. Overall, the data in Table 1 suggest that the established agents that were imported before 1980 tend to have broader host ranges (category 1+2 versus category 3+4 versus category 5+6 [see Table 4]) than those that were imported after 1980 ($\chi^2 = 6.74$, $p = 0.03$, $1 - \beta = 0.63$). We do not yet know whether there is a general trend for non-target effects per introduction to have declined in time, but support from the literature (Lynch and Thomas, 2000; see Henneman and Memmott, 2001) indicates that it is a reasonable possibility.

One of the factors that could increase the probability of non-target effects is the "lottery" approach to biological control, in which biological control agents are released in quick succession against the same target(s), with new agents being introduced before earlier introductions can show effectiveness (McEvoy and Coombs, 2000). The lottery approach causes an expanding gap between number of biological control agents introduced and number of targets over time ("runaway importation-rates"; McEvoy and Coombs, 2000). An expanding gap of this sort appears not only to be present for the Florida data (Frank and McCoy, 1993, Figs. 1 and 2), but also to be even more pronounced in the Florida data than some other examples (cf. McEvoy and Coombs, 2000, Fig. 1). At least part of the reason for the relatively large gap

Table 4
Year(s) of introduction, species introduced, announced target, and level of specificity (L)

Year	Species introduced	Announced target	L
1899	*Rodolia cardinalis* (Mulsant) (Coccinellidae)	*Icerya purchasi* Maskell (Margarodidae)	2
1899	*Scutellista cyanea* Motschulsky (Pteromalidae)	*Ceroplastes cirripediformis* Comstock (Coccidae)	3
1917	*Cryptochetum iceryae* (Williston) (Cryptochetidae)	*Icerya purchasi* Maskell (Margarodidae)	1
1917	*Leptomastidea abnormis* (Girault) (Encyrtidae)	*Planococcus citri* (Risso) (Pseudococcidae)	5
1925	*Harmonia dimidiata* (F.) (Coccinellidae)	*Aphis spiraecola* Patch (Aphididae)	6
1930	*Cryptolaemus montrouzieri* Mulsant (Coccinellidae)	*Planococcus citri* (Risso) (Pseudococcidae)	6
1932	*Alabagrus stigma* (Brullé) (Braconidae)	*Diatraea saccharalis* (F.) (Pyralidae)	2
1932	*Pseudaphycus mundus* Gahan (Encyrtidae)	*Dysmicoccus boninsis* (Kuwana) (Pseudococcidae)	5
		Saccharicoccus sacchari (Cockerell) (Pseudococcidae)	5
1936	*Cryptognatha nodiceps* Marchall (Coccinellidae)	*Aspidiotus destructor* Signoret (Diaspididae)	1
1939	*Coelophora inaequalis* (F.) (Coccinellidae)	*Sipha flava* (Forbes) (Aphididae)	5
1940	*Leptomastix dactylopii* Howard (Encyrtidae)	*Planococcus citri* (Risso) (Pseudococcidae)	5
1944	*Hambletonia pseudococcina* Compere (Encyrtidae)	*Dysmicoccus brevipes* (Cockerell) (Pseudococcidae)	2
1954	*Anagyrus antoninae* Timberlake (Encyrtidae)	*Antonina graminis* Maskell (Pseudococcidae)	1
1957	*Pseudectroma europaea* Signoret (Encyrtidae)	*Antonina graminis* Maskell (Pseudococcidae)	2
1958	*Coccinella septempunctata* L. (Coccinellidae)	Various aphid spp. (Aphididae)	5
1959	*Neodusmetia sangwani* (Subba Rao) (Encyrtidae)	*Antonina graminis* Maskell (Pseudococcidae)	1
1959	*Stenocranophilus quadratus* Pierce (Stylopidae)	*Saccharosydne saccharicida* (Westwood) (Delphacidae)	1
1960	*Aphytis holoxanthus* DeBach (Aphelinidae)	*Chrysomphalus ficus* Ashmead (Diaspididae)	5
1963	*Cotesia flavipes* Cameron (Braconidae)	*Diatraea saccharalis* (F.) (Pyralidae)	2
1965	*Agasicles hygrophila* Selman & Vogt (Chrysomelidae)	*Alternanthera philoxeroides* (Martius) (Amaranthaceae)	1
1967	*Amynothrips andersoni* O'Neil (Paleothripidae)	*Alternanthera philoxeroides* (Martius) (Amaranthaceae)	2
1969	*Aphelinus gossypii* Timberlake (Aphelinidae)	*Aphis gossypii* Glover (Aphididae)	5
1969	*Doryctobracon areolatus* (Szépligeti) (Braconidae)	*Anastrepha suspensa* (Loew) (Tephritidae)	5
1969/99	*Quadrastichus haitiensis* (Gahan) (Eulophidae)	*Diaprepes abbreviatus* (L.) (Curculionidae)	4
1971	*Arcola malloi* (Pastrana) (Pyralidae)	*Alternanthera philoxeroides* (Martius) (Amaranthaceae)	1
1972	*Diachasmimorpha longicaudata* (Ashm.) (Braconidae)	*Anastrepha suspensa* (Loew) (Tephritidae)	5
1972	*Neochetina eichhorniae* Warner (Curculionidae)	*Eichhornia crassipes* (Martius) Solms (Pontederiaceae)	1
1974	*Neochetina bruchi* Hustache (Curculionidae)	*Eichhornia crassipes* (Martius) Solms (Pontederiaceae)	3
1976	*Amitus hesperidum* Silvestri (Platygastridae)	*Aleurocanthus woglumi* Ashby (Aleyrodidae)	1
1976	*Encarsia perplexa* (Huang & Polaszek) (Aphelinidae)	*Aleurocanthus woglumi* Ashby (Aleyrodidae)	5
1976	*Encarsia sankarani* Hayat (Aphelinidae)	*Fiorinia theae* Green (Diaspididae)	2
1977	*Encarsia lahorensis* (Howard) (Aphelinidae)	*Dialeurodes citri* Ashmead (Aleyrodidae)	5
1977	*Niphograpta albiguttalis* Warren (Pyralidae)	*Eichhornia crassipes* Solms (Pontederiaceae)	2
1979	*Aganaspis daci* (Weld) (Figitidae)	*Anastrepha suspensa* (Tephritidae)	2
1979	*Encarsia smithi* (Silvestri) (Aphelinidae)	*Aleurocanthus woglumi* (Aleyrodidae)	5[a]
1981	*Euplectrus puttleri* Gordh (Eulophidae)	*Anticarsia gemmatalis* Hübner (Noctuidae)	1
1981/88	*Larra bicolor* F. (Sphecidae)	*Scapteriscus* spp. (Gryllotalpidae)	3
1984	*Aceratoneuromyia indica* (Silvestri) (Eulophidae)	*Anastrepha suspensa* (Loew) (Tephritidae)	5
1985	*Steinernema scapterisci* Nguyen & Smart (Steinernematidae)	*Scapteriscus* spp. (Gryllotalpidae)	3
1986	*Goetheana shakespearei* Girault (Eulophidae)	*Selenothrips rubrocinctus* (Giard) (Thripidae)	4
1987	*Hydrellia pakistanae* Deonier (Ephydridae)	*Hydrilla verticillata* (Lf.) Royle (Hydrocharitaceae)	2
1987	*Neohydronomus affinis* Hustache (Curculionidae)	*Pistia stratiotes* L. (Araceae)	1
1988	*Ormia depleta* (Wiedemann) (Tachinidae)	*Scapteriscus* spp. (Gryllotalpidae)	3
1994	*Ageniaspis citricola* Logvinovskaya (Encyrtidae)	*Phyllocnistis citrella* Stainton (Gracillariidae)	4
1994	*Cirrospilus ingenuus* Gahan (Eulophidae)	*Phyllocnistis citrella* Stainton (Gracillariidae)	6[a]
1996	*Chilocorus circumdatus* (Schoenherr) (Coccinellidae)	*Unaspis citri* (Comstock) (Diaspididae)	5
1997	*Entedononecremnus krauteri* Zolnerowich & Rose (Eulophidae)	*Aleurodicus dugesii* Cockerell (Aleyrodidae)	1
1997	*Oxyops vitiosa* Pascoe (Curculionidae)	*Melaleuca quinquenervia* (Cavanilles) S.T. Blake (Myrtaceae)	2
1997	*Pseudacteon tricuspis* Borgmeier (Phoridae)	*Solenopsis invicta* Buren (Formicidae)	4
1998	*Coccobius fulvus* (Compere & Annecke) (Aphelinidae)	*Aulacaspis yasumatsui* Takagi (Diaspididae)	5
1998	*Encarsiella noyesi* Hayat (Aphelinidae)	*Aleurodicus dugesii* Cockerell (Aleyrodidae)	3
1999	*Pseudacteon curvatus* Borgmeier (Phoridae)	*Solenopsis invicta* Buren (Formicidae)	4
1999	*Tamarixia radiata* (Waterston) (Eulophidae)	*Diaphorina citri* Kuwayama (Psyllidae)	1
2000	*Diaphorencyrtus aligarhensis* (Shafee, Alam & Agarwal) (Encyrtidae)	*Diaphorina citri* Kuwayama (Psyllidae)	1
2000	*Lipolexis oregmae* (Gahan) (Aphididae)	*Toxoptera citricida* (Kirkaldy) (Aphididae)	5
2002	*Anagyrus kamali* Moursi (Encyrtidae)	*Maconellicoccus hirsutus* (Green) (Pseudococcidae)	2
2002	*Aphytis sankarani* Rosen & DeBach (Aphelinidae)	*Pseudaulacaspis cockerelli* (Cooley) (Diaspididae)	1
2002	*Boreioglycaspis melaleucae* Moore (Psyllidae)	*Melaleuca quinquenervia* (Cavanilles) S.T. Blake (Myrtaceae)	2
2002	*Gyranusoidea indica* Shafee, Alam & Agarwal (Encyrtidae)	*Maconellicoccus hirsutus* (Green) (Pseudococcidae)	2
2003	*Gratiana boliviana* Spaeth (Chrysomelidae)	*Solanum viarum* Dunal (Solanaceae)	1

1, monophagous everywhere (16); 2, monophagous in Florida (14); 3, oligophagous (non-natives) (6); 4, oligophagous (5), 5, hemi-polyphagous (16); and 6, polyphagous (3).

[a] Facultative hyperparasitoid of a biological control agent.

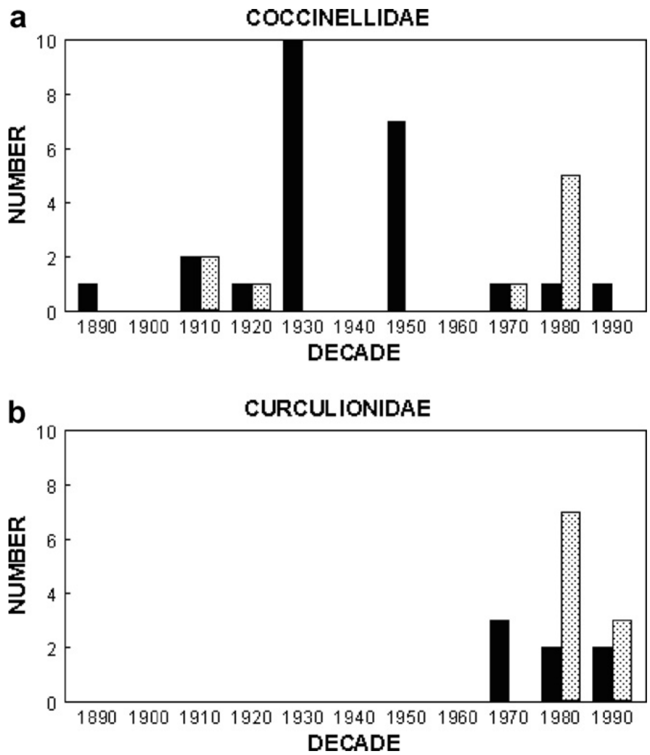

Fig. 1. Records of importation of species of (a) Coccinellidae and (b) Curculionidae into Florida as potential biological control agents. Closed bar, released; dashed bars, not released.

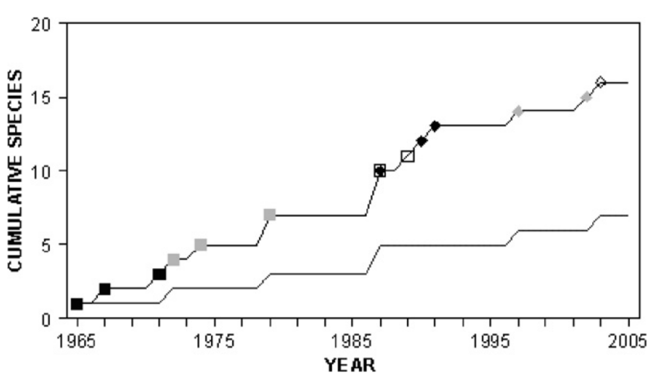

Fig. 2. Cumulative number of classical biological control agents released (upper line) and of target plant species (lower line). Different symbols on the agents' line indicate different target species.

for the Florida data may be the relatively low rate of establishment of classical biological control agents there (Frank and McCoy, 1993). We therefore focused on weed biological control agents because the rate of establishment of this group of agents is much higher, 70–90%, than the overall agent establishment rate (Frank and McCoy, 1993). An expanding gap between the number of biological control agents introduced and number of targets over time remained, suggesting a lottery approach was being used for this group, too (Fig. 2). Overall, the average time between successive releases of agents against the same target is 2.4 years.

Several lines of evidence concerning host ranges of released natural enemies indicate that substantial risk of non-target effects may exist in Florida. We have shown that 42% of the established biological control agents in Florida have native species in their potential host ranges. We also have shown that releases of broadly generalist species have occurred in Florida, but that the number of instances of such releases has declined in recent decades. Finally, we have shown that the lottery approach to biological control has been practiced in Florida.

3.3. What portion of the native biota is susceptible to non-target effects?

Of the 60 established biological control agents, 24 appear to have the potential to affect native Florida non-target species, because of their known host ranges. The potentially susceptible non-target species fall into a small number of families, largely mirroring the families of the target species: Curculionidae (subfamily Entiminae, Coleoptera); Tephritidae (Diptera); Aleyrodidae, Aphididae, Diaspididae, and Pseudococcidae (Homoptera); Formicidae (genus *Solenopsis*, Hymenoptera); Gracillariidae (genus *Phyllocnistis*) and Lyonetiidae (subfamilies Bedellinae and Cemiostominae) (Lepidoptera); and Thripidae (subfamily Panchaetothripinae, Thysanoptera). We discuss what is known about the susceptibility of native species within these families to attack by classical biological control agents in Florida (also see descriptions of the individual biological control agents in Table 1), and estimate the numbers of at-risk species within them, based on the evidence currently available. We treat absence of evidence as evidence of absence.

3.3.1. Curculionidae

Of the various egg-parasitoids of *Diaprepes* weevils released in Florida, it is unclear that any has become permanently established. The most likely agent to have become permanently established is *Quadrastichus haitiensis*, a parasitoid that is known to be able to attack also the eggs of the native species *Pachnaeus litus* (Germar), which feeds on citrus. The agent is not known to attack the congeneric native species *Pachnaeus opalus* (Olivier), which also feeds on citrus, but this species has not been tested for susceptiblity. The weevil subfamily Entiminae includes 35 species, in 21 genera, in Florida, of which 20 species are native (our data compilation). Oviposition by species in this subfamily usually takes place in the soil or rarely on the foliage of the host plant, larvae then dropping to the ground to feed in the soil (Anderson and Howden, 2001, p. 766). *Quadrastichus haitiensis* oviposits in host eggs rolled within leaves, which may account for the apparent limitation of this agent to the genera *Diaprepes* and *Pachnaeus.* The native weevil species *Artipus floridanus* Horn and *Tanymecus confusus* Say, which also feed on citrus, are not known to be attacked by *Q. haitiensis.* We estimate the number of at-risk native species in this family to be the two *Pachnaeus* species.

3.3.2. Tephritidae

Among the tephritid fruit flies are some major pests. Caribbean fruit fly, *Anastrepha suspensa*, after detection and eradication in the 1920s, became established in Florida in the 1960s. Once the Caribbean fruit fly was established, such was its economic importance, particularly in citrus, that biological control agents were imported and released no matter that their natural hosts in various parts of the world are fruit flies of other genera and that they might, therefore, attack native fruit flies. The established biological control agents did not provide a high level of control of Caribbean fruit fly. In Hawaii, two non-target tephritid gall-makers were shown to be attacked by *Diachasmimorpha longicaudata*, which was introduced to control fruit-infesting pests (Duan and Messing, 2000), but these two non-target species had been introduced as classical biological control agents of weeds, and no native tephritids were shown to be attacked (Duan and Messing, 2000). Of the many species of native tephritid fruit flies in Florida, 17 species, in four genera, are fruit and seed feeders (but not on citrus); the others are leaf miners or gall-makers (G.R. Steck, personal communication). The four agents targeting *A. suspensa* that have become established are known to attack various fruit-feeding tephritid fruit flies in their home ranges. Relatively recent attempts to test native species for susceptibility have failed for lack of adequate numbers of individuals to test (G.R. Steck, personal communication). We estimate the number of at-risk native species in this family to be all 17 native fruit and seed feeders.

3.3.3. Aleyrodidae, Aphididae, Diaspididae, and Pseudococcidae

Some adventive pest species in these families have very broad host ranges. For example, among the Aleyrodidae, *Aleurocanthus woglumi* infests more than 300 plant species (although citrus is the most suitable for development of large populations), *Aleurodicus dugesii* infests at least 70 plant species (although hibiscus clearly is the most preferred host), and *Dialeurodes citri* infests at least 30 plant species (although citrus clearly is the most preferred host) (our data compilation). The large number of pest species and their often broad host ranges may have prompted, for example, the importation of coccinellids for control of multiple species or even for control of "aphids," in general (Frank and McCoy, 1993). The coccinellids *Cryptolaemus montrouzieri* (Dactylopiidae, Pseudococcidae) and *Harmonia dimidiata* (Aphididae, Coccidae, Dactylopiidae, Diaspididae, Margarodidae, Pseudococcidae, Psyllidae) appear to pose the greatest threat to non-target Homoptera, but the number of families containing potential non-target species would probably decline if a specific host list were available for *H. dimidiata*.

All species within the seven genera of Aleyrodidae known to be attacked by classical biological control agents in Florida are adventive. Another genus, *Metaleurodicus*, which is closely related to *Aleurodicus*, contains one species, *Metaleurodicus griseus* (Dozier), that could be native, but the species is not known to be attacked specifically. The only recorded hosts of *M. griseus* in Florida are *Eugenia* spp., which have not been recorded as hosts of any of the target species. We do not know whether other native species are within the ecological ambit of the agents affecting target species of Aleyrodidae. Members of this family are not known to be preyed upon by introduced coccinellids in Florida. Without information to the contrary, we estimate that there are no native species at risk in this family.

All of the species within the five genera of Aphididae known to be attacked by classical biological control agents in Florida are adventive. The genus *Rhopalosiphum* contains two species, *Rhopalosiphum arundinariae* (Tissot) and *Rhopalosiphum gnaphalii* Tissot, that we judge to be possibly native, and the genus *Aphis* contains six native species, *Aphis astericola* Tissot, *Aphis caliginosa* Hottes and Frison, *Aphis carduella* Walsh, *Aphis cephalanthi* Thomas, *Aphis iteae* (Tissot), and *Aphis minima* (Tissot) (www.sel.barc.usda.gov/aphid/aphframe.htm). The introduced coccinellid *H. dimidiata* could be a threat to other native species in this family and in other, related, families. We do not know whether any native species are within the ecological ambit of the agents affecting target species of Aphididae, nor do we know the full range of native species potentially at risk from *H. dimidiata.* We estimate the number of at-risk native species in this family to be nine (the listed species and the native target species *Sipha flava*).

All of the species within the nine genera of Diaspididae known to be attacked by classical biological control agents in Florida are adventive (Gillian Watson, personal communication). The introduced coccinellid *Chilocorus circumdatus* apparently preys only on certain adventive species, and on *Coccus viridis* (Coccidae) (www.extento.hawaii.edu/kbase/crop/Type/c_viridi.htm). All members of the genus *Coccus* are adventive in Florida (Miller et al., 2005). We do not know whether any native species are within the ecological ambit of the agents affecting target species of Diaspididae. We estimate the number of at-risk native species in this family to be 0.

All species within seven of the 10 genera of Pseudococcidae known to be attacked by classical biological control agents in Florida are adventive. Two species of *Dysmicoccus*, *Dysmicoccus milleri* Kosztarab and *Dysmicoccus morrison* (Hollinger); one species of *Ferrisia*, *Ferrisia floridana* (Ferris); and two species of *Pseudococcus*, *Pseudococcus maritimus* (Ehrhorn) and *Pseudococcus viburni* (Signoret), are native to Florida. The introduced coccinellid *C. montrouzieri* could be a threat to other native species in this family and in other, related, families [it is known to prey on two native species of *Dactylopius*, *Dactylopius confusus* (Cockerell) and *Dactylopius opuntiae* (Cockerell)]. We do not know whether any native species are within the ecological ambit of the agents affecting target species of Pseudococcidae, nor do we know the full range of native species potentially at risk from *C. montrouzieri.* We estimate the number of at-risk native species in this family to be five (and two in Dactylopiidae).

3.3.4. Formicidae

Solenopsis invicta is closely related to the native Florida species *Solenopsis geminata* (F.) and *Solenopsis xyloni* McCook (Trager, 1991), but *S. xyloni* may have been extirpated from the state (Deyrup, 2003). These two native species of *Solenopsis*, and perhaps other native ants, as well, could be at risk from *Pseudacteon curvatus* and *Pseudacteon tricuspis*, but no-choice tests on them, and on 19 other species of ants, indicate that the risk is small (Porter and Alonso, 1999; Porter, 2000). The several other species of *Solenopsis* in Florida (Deyrup, 2003) probably are not suitable hosts because they are small and do not forage above ground (M. Deyrup, personal communication; J.L. Stimac, personal communication). We estimate the number of at-risk native species in this family to be one (only *S. geminata*).

3.3.5. Gracillariidae and Lyonetiidae

Host specificity testing in Australia indicated that neither *Ageniaspis citricola* nor *Cirrospilus ingenuus* would attack native *Phyllocnistis* leafminers there, but the agent was once reported to attack a native *Phyllocnistis* leafminer in Florida. There may be risk to the six other native species of the genus, although none of them feed on citrus. Perhaps there is risk to non-target lyonetiid (seven species, six of which are native, in five genera) leafminers from *C. ingenuus*, but the only evidence is that this parasitoid was once reported from a lyonetiid leafminer in China. Unfortunately, the one host record from China did not identify the host to species level and we do not know whether it belonged to a group that does not occur in Florida. We suggest that the Chinese record may be based on misidentification, as we suggest is also is true for the Jordanian and Indian records (Table 1) for *C. ingenuus.* No attempts have been made to test native species of either family for susceptibility in Florida. We estimate the number of at-risk native species in these families to be all the 13 species discussed.

3.3.6. Thripidae

Goetheana shakespearei potentially could attack native thrips in the subfamily Panchaetothripinae. Since its introduction (or arrival) in Florida, however, this agent has seldom been collected. Panchaetothipinae from the Florida State Collection of Arthropods (compiled by G.B. Edwards) include 14 species, of which only two species of *Caliothrips*, *Caliothrips floridensis* Nakahara and *Caliothrips multistriatus* Nakahara, appear to be native to Florida. We do not know whether these two species, or other native species, are within the ecological ambit of *G. shakespearei.* We do know, however, that host lists from the Florida State Collection of Arthropods (compiled by G.B. Edwards) show that the many hosts (in about 20 families) recorded for the target species, *Selenothrips rubricinctus*, in Florida are dicots, whereas the hosts recorded for *Caliothrips* spp. are palms and grasses. Without more specific information to the contrary, we estimate the number of at-risk native species in this family to be two.

It seems a reasonable assumption that risk of non-target effects is increased when native species are targets of biological control (see Lockwood, 2000; Strong and Pemberton, 2001). How many of the 38+ targets are native Florida species is difficult to establish. The best available evidence suggests that only one target of an established classical biological control agent in Florida, the aphid *Sipha flava*, is native to Florida (Nuessly, 2005). In Florida, *Sipha flava* was first noticed as a pest in the 1920s, when sugarcane, an introduced crop, was grown commercially in southern Florida (Hall and Bennett, 1994). Several pest targets of unsuccessful biological control programs appear to be native Florida species (Frank and McCoy, 1994), including two genera of Agromyzidae and Sciaridae (Diptera); one genus of Lygaeidae (Hemiptera); one species of Diprionidae (Hymenoptera); and nine species of Geometridae, Lasiocampidae, Noctuidae, and Pyralidae (Lepidoptera). Based on new knowledge, of 16 species called native or possibly native originally (Frank and McCoy, 1993), five are now thought to be adventive. Likewise, two species called adventive originally are now thought to be native. Three additional targets of commercially imported biological control agents (Frank and McCoy, 1994) also are now thought to be native. Proportional establishment of classical biological control agents on native pests has been relatively poor, but this may be because many of the native pests are lepidopterans for which proportionately more failures are reported (Frank and McCoy, 1993).

The evidence concerning the risks of non-target effects on native biota in Florida indicates that this is confined to a relatively small group of species within about 10 families. We have shown that a particularly risky form of introduction, of agents targeting native species, is an uncommon practice in Florida, and that most of these introductions have failed. We have suggested that additional examination of the effects of target species on the native biota is warranted, if risk of biological control is to be assessed fully.

3.4. How frequent are non-target effects of biological control agents and what are the strengths of the non-target effects?

There is little direct evidence of non-target effects of any classical biological control agent in Florida in line with evidence from elsewhere (e.g., Lynch and Thomas, 2000; also see McFadyen, 1998). Part of the reason for this is that researchers simply have not looked systematically for it (Barratt et al., 2000; McEvoy and Coombs, 2000; Hoddle, 2004), although the probability of an introduced parasitoid being recorded on at least one native host has not been shown to increase over time (Hawkins and Marino, 1997), as might be expected if lack of effort were a problem. Despite the risks from the introduction of biological control agents with native species in their potential host ranges, according to the records we have accumulated, virtually no non-target effects have been documented. We looked carefully, therefore, at cases documented in the literature.

Lynch and Thomas (2000) listed all of the worst cases of non-target effects produced by classical biological control agents that they could locate. Their list includes 17 introductions of 14 agents. Although only one case related directly to Florida, six of the agents were released or planned for release in Florida. *Aphytis holoxanthus* (Hymenoptera: Aphelinidae) affected two non-target species severely (6/9 on a severity scale; Lynch and Thomas, 2000) in Brazil and the US (Florida, Texas), by displacing native parasitoids of the target. The Florida example misrepresented the non-target effect by failing to note that the native parasitoid is alive and well on its normal host (Bennett, 1993) (see explanation under *A. holoxanthus* in Table 1). *Cotesia flavipes* (Hymenoptera: Braconidae) affected three non-target species severely (6/9) in Brazil and Mexico, again by displacing native parasitoids of the target (Bennett, 1993). This agent also has affected non-target species elsewhere, but no such effects have been reported from Florida since its release in 1963 (see above). *Coccinella septempunctata* (Coleoptera: Coccinellidae) affected three non-target species moderately-severely (5/9) and another non-target species moderately (3/3) in the US (South Dakota and elsewhere), by interfering with other coccinellid species (Elliott et al., 1996; Wheeler and Hoebeke, 1995). The agent was released in Florida in 1958 and subsequently, and it now is widespread, although it is uncertain whether the presence of this species anywhere in North America resulted from biological control introductions or from immigrations (see above). Non-target effects have not been demonstrated in Florida, but the possibility deserves investigation. *Cryptolaemus montrouzieri* (Coleoptera: Coccinellidae) preyed upon one non-target species moderately (3/9) in Mauritius and South Africa, where it (the non-target) had been imported for weed control (Goeden and Louda, 1976). The agent was released in Florida in 1930, and may feed on various coccids, three of which appear to be native (see above). Non-target effects have not been demonstrated in Florida, but the possibility deserves investigation. *Compsilura concinnata* (Diptera: Tachinidae) attacked one non-target species moderately (3/9) in the US (Stiling and Simberloff, 2000), and is well-known to be particularly threatening to native species where it has been introduced (e.g., Hawkins and Marino, 1997; Boettner et al., 2000). The agent was released in Florida in 1915–16, but failed to establish (Frank and McCoy, 1993). *Trichopoda pilipes* (Diptera: Tachinidae) attacked one non-target species moderately (3/9) in the US (Hawaii) (Follett et al., 2000). The agent was imported to Florida in 1972–73, but was probably not released (Frank and McCoy, 1993). The agent targeted *Nezara viridula* (Pentatomidae) in both Hawaii and Florida. After release in Hawaii, it was found also to attack some non-native pentatomids, but not native ones (Follett et al., 2000). This agent did attack a native scutellarid, however, apparently reducing reproductive output of the host (Follett et al., 2000). A native species of *Trichopoda*, *Trichopoda pennipes* (F.), occurs in Florida.

The evidence of frequency of non-target effects in Florida indicates that such effects are, at least, rare. None of the established biological control agents that have been introduced into Florida against weeds has been shown to harm native species. This conclusion does not obviate the possibility that native species have been harmed, or that native species may be harmed in the future, by existing or future agents. There is no reason to suggest that Florida's biological control practitioners were any more or any less careful than others elsewhere, but perhaps they were simply lucky in avoiding environmentally-damaging mistakes. Some generalists were indeed imported, especially in the early years, but potentially harmful species luckily failed to establish. We suggest that retrospective field evaluations of the effects of the agents categorized as levels 5 and 6 (Table 4) be undertaken. These field evaluations should focus on the relationships of the agents with native citrus weevils, tephritid fruit flies, aphids, mealybugs, soft scales, armored scales, whiteflies, *Phyllocnistis* and lyonetiid leafminers, and panchaetothripine thrips. Particular effort may need to be directed at the native lepidopterans and those native species susceptible to predation by coccinellids. Information on past non-target effects will help estimate the likelihood of non-target effects in the future.

3.5. A rudimentary assessment of the number of direct non-target effects that have been missed

If non-target effects have been missed through lack of searching, how many undetected effects are likely in Florida? To address this question we used literature-based estimates of rates of non-target effects and likely numbers of potential non-target hosts and the data presented in this review to derive the likely number of missed direct non-target effects. To address the high degree of uncertainty, we used two methods.

Method 1 assumed that 27.3% of introduced agents targeting insect hosts and 91.7% of introduced agents targeting plant hosts result in establishment (Frank and McCoy, 1993), that established agents are twice as likely to cause non-target effects as agents that do not establish (Hawkins and Marino, 1997), that agents targeting plant hosts are 1/3 again as likely to cause non-target effects as agents targeting insect hosts (Stiling and Simberloff, 2000), that between 1.7% (Lynch and Thomas, 2000) and 22.1% (Stiling and Simberloff, 2000) [another estimate of 16.3% (Hawkins and Marino, 1997) is within this range] of introductions result in non-target effects, that between 10% (Lynch and Thomas, 2000) and 20% (Stiling and Simberloff, 2000) of non-target effects lead to population change in non-target species, and that 36% of the population changes are significant (Lynch and Thomas, 2000). The calculation was:

a. Starting numbers: 49 established agents targeting insects, 11 established agents targeting weeds

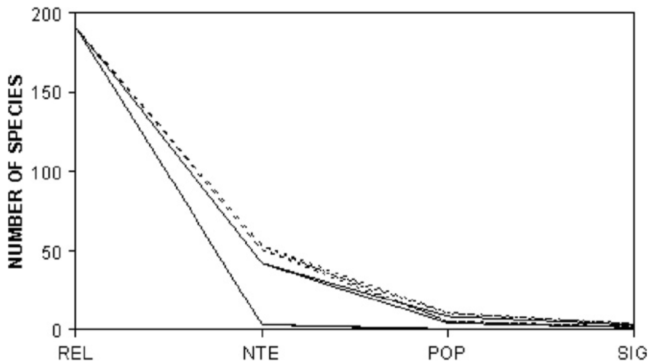

Fig. 3. Number of native species expected to display non-target effects. Solid lines and dashed lines represent expectations calculated in two different ways (see text). REL, agents released, NTE, all non-target effects, POP, non-target effects leading to population change, SIG, non-target effects leading to significant population change.

b. Determine how many original introductions: $= 49 \div 0.273 = 179$ (insects); $= 11 \div 0.917 = 12$ (weeds)

c. Compute non-target effects, scaling for $2\times$ contribution of established agents conservatively by using 1.7% and 22.1% for established agents:
$= [(\{2 \times 49 + 130\} \div 179) \times 0.017] \times 179 = 3.88$ (low for insects)
$= [(\{2 \times 49 + 130\} \div 179) \times 0.221] \times 179 = 50.40$ (high for insects)
$= [\{2 \times 11 + 1\} \div 12) \times 0.017] \times 12 = 0.39$ (low for weeds)
$= [\{2 \times 11 + 1\} \div 12) \times 0.221] \times 12 = 5.08$ (high for weeds)

d. Scale for "one-third again" effect of agents targeting weeds:
$= [0.39 \times 16 + 3.88 \times 179] \div 191 = 3.67$ (low)
$= [5.08 \times 16 + 50.40 \times 179] \div 191 = 47.23$ (high)

e. Compute number of population changes:
$= 3.67 \times 0.10 = 0.37$ (low, low)
$= 3.67 \times 0.20 = 0.73$ (low, high)
$= 47.23 \times 0.10 = 4.72$ (high, low)
$= 47.23 \times 0.20 = 9.45$ (high, high)

f. Compute number of significant changes
$= 0.37 \times 0.36 = 0.13$ (low, low)
$= 0.73 \times 0.36 = 0.26$ (low, high)
$= 4.72 \times 0.36 = 1.70$ (high, low)
$= 9.45 \times 0.36 = 3.40$ (high, high)

Method 2 was [proportion of introductions that established × proportion with non-target native hosts × number of potential non-target native hosts × proportion leading to population change × proportion leading to significant population change × number of introductions]. Method 2 assumed that 27.3% of introduced agents targeting insect hosts and 91.7% of introduced agents targeting plant hosts result in establishment, that 48% of established agents targeting insect hosts and 0.0% of established agents targeting plant hosts have native potential hosts (this paper), that agents that do not establish are 33% less likely to have native potential hosts (Hawkins and Marino, 1997), that each agent has between (0.53 non-target species per pest species × 50/32 agents per pest species) = 0.83 (Stiling and Simberloff, 2000) and 0.87 (this paper) native potential non-target hosts, that between 10% and 20% of introductions lead to population change in non-target species, and that 36% of the population changes are significant.

We make no claim that either result is correct, but we do assume that the results bracket the correct number, given the current level of knowledge. The results of these computations suggest that fewer than 10 releases of introduced biological control agents in Florida are likely to have produced population changes in non-target species, and that fewer than four of the 10 are likely to have produced substantial population changes (Fig. 3). Of course, these expected numbers very much depend on the way in which they were generated. A particularly influential value in the equations generating these small numbers of changes is the 10–20% of introductions expected to lead to population change. If our results are even approximately correct, then the small number of significant population changes in native non-target species that are expected to occur might explain, in part, why non-target effects could be overlooked in Florida. As well, these effects could have been transient, making them even more likely to be overlooked.

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