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Introduction to Insect Behavioral Ecology : The Good, the Bad, and the Beautiful: Non-Indigenous Species in Florida. Invasive Adventive insects and Other Organisms in Florida

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INTRODUCTION TO INSECT BEHAVIORAL ECOLOGY : THE GOOD, THE BAD, AND THE BEAUTIFUL: NON-INDIGENOUS SPECIES IN FLORIDA

INVASIVE ADVENTIVE INSECTS AND OTHER ORGANISMS IN FLORIDA.

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ABSTRACT

An excessive proportion of adventive (= "non-indigenous") species in a community has been called "biological pollution." Proportions of adventive species of fishes, amphibia, reptiles, birds and mammals in southern Florida range from 16% to more than 42%. In Florida as a whole, the proportion of adventive plants is about 26%, but of insects is only about 8%. Almost all of the vertebrates were introduced as captive pets, but escaped or were released into the wild, and established breeding populations; few arrived as immigrants (= "of their own volition"). Almost all of the plants also were introduced, a few arrived as immigrants (as contaminants of shipments of seeds or other cargoes). In contrast, only 42 insect species (0.3%) were introduced (all for biological control of pests, including weeds). The remainder (about 946 species, or 7.6%) arrived as undocumented immigrants, some of them as fly-ins, but many as contaminants of cargoes. Most of the major insect pests of agriculture, horticulture, human-made structures, and the environment, arrived as hitchhikers (contaminants of, and stowaways in, cargoes, especially cargoes of plants). No adventive insect species causing problems in Florida was introduced (deliberately) as far as is known.

The cause of most of the so-called biological pollution is the public's demand for "pet" animals and "ornamental" plants of foreign origin, the public's environmental irresponsibility in handling these organisms, the dealers' willingness to supply these organisms for cash, and governments' unwillingness to stem the flow of a lucrative commerce. The cause of almost all of the remaining part is flight, walking, swimming, and rafting from adjoining states and from nearby countries in the Caribbean, Mexico and Central America. The introduction of specialized insect biological control agents, although it contributes to biological pollution, appears to be an environmentally-sound solution to the much greater biological pollution caused by immigrant insects and introduced plants in Florida. Greater concern for insects as living things, or as integral parts of nature, coupled with increased understanding of how problem insects get into Florida, may foster a more even-handed approach to the reduction of biological pollution.

Key Words: Adventive species, biological pollution, immigrant species, insects and commerce, introduced species.

RESUMEN

Una proporción excesiva de especies foráneas (=no indígenas) en una comunidad ha sido denominada "polución biológica". Las proporciones de especies foráneas de peces, anfibios, reptiles, aves, y mamíferos en el sur de la Florida varían del 16 al 42%. En la Florida en su totalidad, la proporción de plantas foráneas es de alrededor del

26%, mientras que la de insectos es de sólo el 8%. Casi todos los vertebrados han sido introducidos como animales de compañía, los cuales escaparon o fueron soltados en espacios naturales y se establecieron como poblaciones reproductivamente viables. Muy pocas especies llegaron como inmigrantes (= "por su propia voluntad"). Casi todas las plantas han sido introducidas, pero llegaron como inmigrantes o como contaminantes en importaciones de semillas. Sin embargo, sólo 42 especies de insectos (0.3%) han sido introducidos y todos como control biológico de plagas, incluyendo malas hierbas. El resto (aproximadamente 946 especies, ó 7.6%) llegó como inmigrantes desconocidos, algunos de ellos volando y muchos como contaminantes en cargamentos. La mayoría de los insectos perjudiciales para la agricultura, horticultura, construcciones humanas y el medio ambiente llegaron como "polizones" (contaminantes de, almacenados en, cargamentos, especialmente cargamentos de plantas). Parece ser que ningún insecto foráneo que cause problemas en la Florida fue introducido (deliberadamente).

La causa mayor de la llamada polución biológica es la demanda del público de animales de compañía y plantas ornamentales de origen extranjero, la irresponsabilidad del público manejando estos organismos, la avidez de los comerciantes en proporcionar dichos organismos a cambio de dinero y la reticencia de los gobiernos en cortar la avalancha de negocios lucrativos. Las causas del resto de la polución biológica estan fundamentadas casi en su totalidad en el desplazamiento en vuelo, por vía terrestre, a nado y en estructuras a la deriva desde los países vecinos caribeños, México, y Centro América. La introducción de insectos especializados en el control de plagas, aunque contribuya a la polución biológica, parece ser una solución medioambiental de peso al problema más grave de la polución biológica producida por los insectos y plantas llegados a la Florida como inmigrantes. Una preocupación mayor por los insectos, como entidades vivas, o como partes integrales de la naturaleza, emparejada con un incremento en el conocimiento sobre cómo los insectos problemáticos entran a la Florida, puede favorecer una estrategia más equilibrada para la reducción de la polución biológica.

Florida's flora and fauna are threatened by a burgeoning human population, approaching 14 million, with a growth rate triple that of the USA during the last decade. By the year 2020, this population could grow to 23 million. The Everglades are said to be dying due to water shortage and pollution. Florida Bay, at the tip of the peninsula, is threatened by enormous algal blooms said to be due to pollution from agricultural lands, and more than 40,000 ha of seagrasses and sponges are dead. Coral reefs are said to be dying from pollution and disturbance. Of 25 shrimp boats operating from Marathon in the early 1970s, there now are none. In the Tampa Bay area, wellfields have been over-pumped, drying up thousands of hectares of wetlands. In central Florida, lakes are said to be polluted with pesticides, causing, for example, a dramatic drop in the largemouth bass population and a 90% decline in the alligator population of Lake Apopka. On the east coast, from Fernandina Beach in the north to Miami Beach in the south, coastal erosion is said to be fueled by overpopulation: about $450 million have been spent pumping sand onto beaches since 1965 to replace the tons eroded by storms. Pollution in the Gulf of Mexico has made bacterial infection from eating raw oysters a frequent health risk. The conch population in the Caribbean has declined by 90% in the past 20 years, and edible marine fish populations on the east coast mirror this decline.

Millions of hectares of Florida no longer even remotely resemble a pristine state. They are now urban landscapes with buildings and roads and ornamental plants, or

agricultural landscapes modified to support the human population, or salt marshes modified to suppress their natural mosquito populations so that humans will not be bitten. All of these changes have supplanted the natural plant and animal populations. All major agricultural crops, farm animals, and popular pet animals in Florida, from citrus to corn to cattle to cats, are introduced. Of all plants of foreign origin that are imported into the USA, 85% arrive through Miami International Airport. Miami also is the busiest US port for fish and wildlife. The root cause of what has been termed the "biological pollution" (McKnight 1993) of Florida is the public's desire for animals and plants of foreign origin, the public's environmental irresponsibility, dealers' ability to earn money by satisfying this desire, and governments' unwillingness to intervene substantially in this profitable commercial activity (Belleville 1994).

In southern Florida, especially, untrammeled whims of humans have introduced so many species of non-farm animals (mainly as "pets") that the native fauna is greatly diluted. Running wild in Dade and Broward Counties have been piranhas, walking catfish, blue tilapia ("introduced from Africa in 1961 by officials of the Game and Freshwater Fish Commission"), electric eels, little barbed Amazonian catfish that swim up [human] urinary tracts, and other fish ("23 exotic fish now breeding in the wild"), Cuban anoles, iguanas, Asian water monitors, caimans, boa constrictors, pythons, mambas ("people want the newest animals as pets"), red-whiskered bulbuls, monk parakeets, howler monkeys, gibbons, green African savannah monkeys, crab-eating macaques, and a herd of 300 buffalo (Belleville 1994). Nine years ago, the fauna of southern Florida included the following percentages of species introduced almost entirely by the pet trade: fishes (16%), amphibians (22%), reptiles (42%), mammals (23%) (Ewel 1986). The percentage of birds is obscured under a category called "free-flying exotics" but, with 16-17 species of parrots and many other species established, it may exceed the percentage of any of the other classes. Recent estimates compiled for all of Florida (US Congress 1993) suggest the percentages of established adventive vertebrate species exceed 20% for most groups. Many such "pet" animals escaped from their owners, or were released deliberately, into the wild. Animals shipped from Florida also have caused problems. For example, red-eared turtles are shipped to France, Belgium, the Netherlands and Germany; over 500,000 individuals are shipped to France alone per year. Some inevitably escaped into the wild where they displaced native turtles (Simons 1994).

Importers of non-crop plants (mainly as "ornamentals") likewise have contributed to dilution of the native flora. Among the worst weeds (Exotic Pest Plant Council 1993) are punk trees, introduced to Florida "to drain wetlands"; water hyacinth, "imported for its pretty, orchidlike blossom"; hydrilla, "a frilly little plant in aquariums"; and Australian pine, "introduced as an ornamental" (Belleville 1994); others include Brazilian pepper, kudzu vine, and cogon grass, all introduced (deliberately). The USDA and Fairchild Botanical Gardens had active programs to introduce tens of thousands of plants of foreign origin for no reason essential to human existence. At present, about 27% of the total established flora of Florida is comprised of adventive species (Table 1). Waiting in the wings, some 25,000 introduced plant species are grown in cultivation, but are not **yet** established in nature (Table 1). Florida is not only a beneficiary of plants of foreign origin, but a donor, and it also donates pest insects infesting ornamental plants (Miller 1994).

The purpose of this introduction is to show what problems adventive species of insects cause in Florida (also see US Congress 1993). These species are placed into a framework that categorizes them to show which ones were **introduced**, and estimate how many arrived without invitation, i.e., were **immigrants**. We also pose some philosophical questions about introductions of insects and other organisms to Florida.

TABLE 1. A COMPARISON OF THE FLORIDA FLORA AND FAUNA

Type	Plants	Insects
Indigenous species	2,525[a]	11,512[c]
Adventive species		
Species immigrant to Florida and established in nature	0[f]	946[c]
Species introduced to Florida and established in nature	925[a,f]	42[d]
Species now cultivated, but not established in nature	25,000[b]	5[e]

[a]after Ward (1989), [b]after comments by David Hall and Thomas Sheehan, [c]estimates explained in Frank & McCoy (1995), [d]biological control agents, after Frank & McCoy (1993), [e]house crickets and mealworms as fishbait, honey bees, silkworms, and a mantis, [f]some of the plants reported by Ward (1989) as "introduced" may, in fact, be immigrants, because it is scarcely conceivable that some of the weeds among them were introduced deliberately, and their seeds may have arrived on the wind, in sea-drift, or as contaminants of shipments of other seeds or materials.

THE CURRENT STATUS OF ADVENTIVE INSECT SPECIES IN FLORIDA

Nomenclature

A distinction is made in this paper between **immigration** and **introduction**, following Frank & McCoy (1990). **Immigrants** arrive of their own volition, even if as stowaways in cargoes, and have **no** permit for their entry into Florida. The word **introduced** is restricted to purposely-introduced species, following Zimmerman (1948). A Florida permit (DPI-FDACS) is now required for **introduction** of **any** insect species into Florida, and in many examples a federal permit (USDA-APHIS-PPQ or USDA-APHIS-VS or USPHS-CDC) also is required. **Adventive** species (elsewhere called non-indigenous species) are those that immigrated together with those that were introduced.

Recognition of Adventive Species

Assessment of adventive insect species in Florida is complicated by a very imperfect knowledge of indigenous species (see Frank & McCoy 1995). There is no baseline information on insects from the time of the rediscovery of the Americas by Columbus, nor from the time of the American revolution. Only for a few (mainly pests) is there information from even 100 years ago, and some are not yet recorded at all. There are now manuals on the Florida species of a few insect families. An enormous amount of taxonomic research still is required, especially on species that are not pests. This research is progressing at a snail's pace because it has little popular appeal, and public funds to support it are virtually unavailable.

The extreme south of Florida presents a special problem as to which species are adventive. Many West Indian insects inhabit the Florida Keys and adjacent mainland. The major part of the range of these species is in Cuba or other islands, and they also inhabit a small part of Florida. Lack of baseline data for some species from 20 years ago, much less 200 years ago, makes it impossible to state how long they have been in Florida. Some species undoubtedly become extinct in Florida from time to time, and then recolonize by flight and winds from the south. Six of them are butterflies: *Chlorostrymon maesites* Herrich-Schaeffer, *Eunica tatila* Herrich-Schaeffer, *Strymon acis* Drury, *Eumaeus atala* Poey, *Heraclides aristodemus* (Esper), and *Anaea*

troglodyta F. Other insect species are so poorly studied that when they are reported for the first time from Monroe County or Dade County, they are recorded as immigrants simply because there is no earlier information. However, the six butterfly species are listed among Florida's rare and endangered invertebrate animals. There is unequal treatment under the law because butterflies have popular appeal, so there is more information about them. Inadequate knowledge of the insect fauna of Cuba and the Bahamas compounds the problem. Florida-based entomologists were discouraged for years from working in Cuba for political reasons.

Records of Adventive Species

Systematic knowledge about Florida's insect fauna is woefully inadequate (see Habeck 1987), because the almost exclusive demand from the public has been on methods for controlling pest species. No agency of the Florida government has a program providing grants for taxonomic research on non-pest species of insects. Although these insects are considered to be wildlife by the US Fish and Wildlife Service (USFWS), they are not considered to be wildlife by the Florida Game and Fresh Water Fish Commission (FGFWFC). Consequently, the Non-Game Wildlife Program of FGFWFC rarely makes funds available for research on them. Professional entomologists were hired in Florida almost entirely to solve problems caused by pest insects. The Florida Department of Agriculture and Consumer Services (FDACS) responded to the need for knowledge on insect fauna in general by housing the Florida State Collection of Arthropods in Gainesville, by paying publication costs for taxonomic work on non-pest species (should someone be willing to write them), and by encouraging donation of specimens to the collection. The Institute of Food and Agricultural Sciences of the University of Florida pays publication costs for work by students and employees on non-pest species, but does not encourage such research.

As a consequence of the emphasis on pest insects, families containing pests [e.g., Culicidae (mosquitoes) and Diaspididae (armored scale insects)] are well known, but families containing mostly innocuous insects are not. The sole exception is the group of families (Nymphalidae, Papilionidae, Pieridae, etc.) called butterflies. Therefore, there is no thorough catalog of the insect fauna of Florida. Although many hundreds of immigrant species now exist in Florida, they are yet a fairly small percentage (under 9%) of the total number of species (Table 1). For example, only four of the 78 mosquito species are immigrants (Frank & McCoy 1995). The proportion is likely to be higher among plant-feeding insects than among non-plant-feeding insects, because many pests of plants have immigrated with imported shipments of plants. The proportion of introduced species is less than half of 1% (Table 1).

Extremely few populations of insect species are monitored routinely in several Florida localities: almost the sole exceptions are some mosquitoes. Most populations are noticed only when their numbers are very high, and cause damage to ornamental plants, crop plants, structures, livestock, and other human possessions. The task of annual monitoring of more than 12,500 insect species (Frank & McCoy 1995) is vastly beyond current capabilities, so there is virtually no information on most adventive insects in Florida.

Recognition that many of the major pests of North American crops were adventive, and probably had immigrated with infested shipments of plants, led to the Federal Plant Quarantine Act of 1912 (Sailer 1978). The act was designed to bar the importation of cargoes infested with plant-feeding insects, through inspection at ports. Much harm had already been caused to agriculture by such immigrant pests. Implementation of the law, however, merely slowed the establishment of immigrant insect species,

and did not prevent it (Sailer 1978). USDA-APHIS inspectors at US ports and airports in fiscal year 1980 intercepted over 18,000 infested shipments (Frank & McCoy 1992).

Unlike the northern parts of the USA, Florida contends not only with infested shipments, but also with flight of insects from the West Indies. Assessment of the literature showed 271 immigrant insect species reported for Florida for the first time between 1971 and 1991 (Frank & McCoy 1992). These were living in Florida when found, and the information gives a rough measure of the current rate of establishment of immigrant species. Relatively few insect species are introduced under permit (Frank & McCoy 1993, 1994).

Major Pathways of Arrival of Adventive Species

Immigrant species: fly-ins. Florida's northern and western borders are permeable to flying and walking insects. Many of Florida's insect species (including pests) are shared with neighboring states for this reason. A familiar example is the love bug (*Plecia nearctica* Hardy). This is a Mexican and Central American species which extended its range to include the Gulf Coast of the USA. Moving into Florida from Alabama in 1949, its population spread to southern Florida in 1975 (Buschman 1976). A large proportion of the insect species of southern Florida arrived by flight, perhaps assisted by winds, from the West Indies, the Bahamas, and the Yucatan peninsula of Mexico. Even wingless species may have arrived by rafting on floating driftwood. Arrival of additional species by flight will continue indefinitely. An aphid which may arrive soon from Cuba (it colonized Cuba from Central America), is *Toxoptera citricida* (Kirkaldy), a vector of tristeza disease of citrus. There is no way of preventing such immigration, although some immigrants from the south, if detected soon after they arrive, may be eradicated by use of chemicals.

Immigrant species: stowaways. More than 25,000 adventive species of plants now grow in Florida (Table 1). Every imported shipment of plants offers opportunity to plant-feeding insects to immigrate as stowaways. Despite the efforts of shippers and inspectors, such plant-feeding insects continue to immigrate. These insects tend to be the most important pests of the introduced plants, but some of them turn their attention to related, indigenous plants. Thousands of shipments are discovered every year to contain insect stowaways, but only a tiny percentage of shipments is inspected at ports and airports. Furthermore, Miami International Airport receives 85% of all shipments of plants to the USA. These, along with shipments of other kinds of cargoes that arrive by air, sea, and land, have been, and continue to be, the main method of immigration of Florida's most important adventive pest insects (Frank & McCoy 1992).

Introduced species: commerce in insects. There has been enormous commerce in introduced plants, and some of these plants have become weeds. In contrast, there has been very little commerce in insects introduced for purposes other than biological control, except for European honey bees (*Apis mellifera* L.) and, to a trivial extent, oriental silkworms (*Bombyx mori* L.). Much more recently, other insects, including a Chinese mantis (*Tenodera aridifolia* Stoll), a Madagascan cockroach (*Gromphadorhina* sp.), a European cricket (*Acheta domesticus* (L.)), and a giant mealworm of unknown origin (*Zophobas* sp.), have been imported and sold to the public as pets, or for educational purposes, or as fishing bait; their owners sometimes release them into the wild, or they escape (Frank & McCoy 1994). Some adventive butterflies are imported for living displays by commercial butterfly zoos, but are not intended for release into the wild (Frank & McCoy 1994). There is no evidence that any of these spe-

cies have established populations in nature in Florida or have caused environmental harm. To reduce future risk from this avenue, such importations are now allowed only after review and under permit from the Division of Plant Industry, FDACS (Florida Administrative Code 1993).

Twenty-one insect species adventive to Florida have been imported commercially as biological control agents since 1980. At least four of these already have established populations in Florida, and some others are indigenous to other parts of the USA (Frank & McCoy 1993, 1994). None of these species has been reported to cause environmental damage. Importations of biological control agents from abroad are allowed only after Federal review and under Federal permit. Florida, virtually alone among the States, now requires its own review and additional permit from the Division of Plant Industry, FDACS (Florida Administrative Code 1993); furthermore, Florida requires this permit even for importations from other parts of the USA. It is to the advantage of the companies selling biological control agents that these species **do not** establish populations in Florida, or at least are not able to sustain large populations, because such populations could eliminate or reduce repeated sales.

Introduced species: importations by government and universities for biological control of pests. These are non-commercial introductions of species which initially are imported under permit into secure quarantine laboratories. If, after testing, they prove to be specific natural enemies of targeted pest species, then a second round of permits is required before their progeny may be released into nature. Targets are pest insects and weeds, and most of these are immigrants (Frank & McCoy 1993). This is the most tightly regulated of all forms of introductions of animals: insects imported into Florida from abroad require Federal (USDA) and State (DPI) permits for importation to quarantine, and Federal and State permits for release into the wild. They may also need documentation of importation as wildlife from the USFWS, and may need various export permits from their countries of origin (depending upon the laws of the country in question).

Despite all the testing and paperwork, most introduced biological control agents do not establish populations. Records show that 151 insect species have been released in Florida as biological control agents, 139 of them against pest insects and 12 against weeds (Frank & McCoy 1993). Among those that became established (34 against insects, 8 against weeds), some proved highly beneficial. Examples are the minute wasps *Amitus hesperidum* Silvestri and *Encarsia opulenta* (Silvestri) that now control citrus blackfly, and the flea beetle *Agasicles hygrophila* Selman & Vogt that now controls alligatorweed. Although regulations governing introduction of insect biological control agents were less stringent 50 years ago, none of the 42 introduced species has been shown to have detrimental effects on the environment.

Problems Caused by Adventive Species

Immigrant insect species annually cause hundreds of millions of dollars in damage to agriculture (including livestock and forestry), horticulture, and structures in Florida. Research into these problems is supported by public and private funds, but the system is being swamped by the high arrival rate of immigrant pests. The following problems, especially notable because of their occurrences on public lands, are the principal ones that we can identify. The only realistic hope for a long-term solution to any of these problems is through introduction of biological control agents (Tschinkel 1993, Frank & Thomas 1994).

Tillandsia bromeliads. *Metamasius callizona* (Chevrolat) is a weevil native to Mexico and Central America. In 1989 it was discovered on introduced bromeliads in

a nursery in Broward County. Surveys were made, and weevils were found on public lands throughout Broward County and in Dade and Palm Beach Counties, and on private lands in Lee County. Populations of the indigenous bromeliad *Tillandsia utriculata*, which is protected under State law, have been decimated in Broward County parks. The weevil also kills the indigenous *Tillandsia paucifolia* and *Tillandsia fasciculata*, and is too widespread to eradicate by the use of chemicals. It seems inevitable that populations of these protected plants will decline drastically throughout their range in Florida (Frank & Thomas 1994), and they are candidates for listing as endangered.

Introduced Ficus spp. Over 60 exotic *Ficus* (fig) species have been introduced into southern Florida as ornamentals. It was thought that none of these species would set viable seed because each is pollinated only by its own species of agaonid wasp, and the wasps were not introduced. But, *Ficus altissima* Blume, *F. benghalensis* L., and *F. microcarpa* L., are now weeds because they are pollinated routinely by immigrant agaonid wasps. Fertile seeds of these enormous trees now germinate in Dade and Monroe counties. Seedlings sprout in public and private lands and on structures, such as highway bridges, where they pose a maintenance problem, because they can destroy the structures as they grow. They are invasive on public lands. There is evidence that the pollinating wasps of *Ficus microcarpa* arrived in seeds brought from Hawaii, and there is concern that fruits (and thus seeds) of the other two fig species are being spread by introduced parrots (Nadel et al. 1992).

Endangered cacti. *Cactoblastis cactorum* Bergroth is a moth, native to South America, whose larvae feed on *Opuntia* cacti. Introduced into Australia in 1925, it saved 12 million acres of pasture land that had been rendered useless by infestation with two species of *Opuntia* unwisely imported from the Gulf of Mexico coast. Between 1957 and 1970, it was introduced into Nevis, Montserrat, Antigua, and Grand Cayman, where *Opuntia* spp. were weeds. From those islands it spread to Puerto Rico, Haiti, the Dominican Republic, and the Bahamas, and in 1989, was found in the Florida Keys (Habeck & Bennett 1990). Unfortunately, in the Florida Keys, it places the rare cacti *Opuntia spinosissima* Martyn (Mill.) and *Opuntia triacantha* (Willdenow) at risk. *Cactoblastis* probably arrived in Florida as a contaminant of *Opuntia* imported as ornamental plants. Inter-island flight or stowing away aboard boats are less likely means of arrival. Deliberate importation as a biological control agent for *Opuntia* cacti, by some member of the public, is still less likely.

Endangered morning glories. Florida's endangered species of morning glories are *Ipomoea microdactyla* (Grisebach) and *Ipomoea tenuissima* Choisy. Sweetpotato (*Ipomoea batatas* Lamarck) is a relative. These plants face a new threat: the tortoise beetle *Chelymorpha cribraria* (F.) This leaf-feeding beetle was discovered in Broward County in 1993, and its range had spread to Dade County's Matheson Hammock Park by March 1994 (Thomas 1994). The beetle is native to South America and the West Indies. Importation of infested sweetpotato is a likely means of arrival.

Fire ants. *Solenopsis invicta* Buren, inaptly termed "the red imported fire ant," arrived in the southern USA about 1940 as an immigrant from South America. Gradually it spread throughout the south, in part by flight, and in part as a contaminant of cargoes. In agricultural ecosystems it inflicts important mortality on such pests as sugarcane borer, boll weevil, and horn fly, but also destroys indigenous natural enemies of these and other pests. It has displaced populations of native ants in disturbed habitats and it kills nestling birds, but its effect on undisturbed public lands may be much less than on disturbed lands (Tschinkel 1993).

Conflicts Caused by Adventive Species

The means of arrival of immigrant species often is obscure. By definition they were not introduced under permit, so there are no records of introduction. An example is *Cactoblastis cactorum*. This moth was introduced to Australia deliberately, to combat *Opuntia* cacti. These plants had been introduced to Australia deliberately for horticultural reasons, but became invasive and caused great losses to agricultural interests. Agriculture was in conflict with horticulture, but public interests were on the side of agriculture. Introduction of the moth to Australia, and its successful control of *Opuntia*, were viewed as highly beneficial.

Cactoblastis was introduced into Nevis, Montserrat, Antigua, and Grand Cayman to suppress *Opuntia* on agricultural lands, and the introductions were requested by the governments of those islands. *Cactoblastis* was not introduced into Puerto Rico, Haiti, the Dominican Republic, or the Bahamas by their governments. Either the moth was smuggled to these islands by private agricultural interests to combat *Opuntia* species that were viewed as weeds, or it flew there from the other islands or hitchhiked on boats.

The situation is more complex in Florida. Horticultural interests have imported *Opuntia* cacti into Florida as ornamental plants, and some of these imported plants are known to have been infested with *Cactoblastis*; this is by far the most likely means of arrival. There are private agricultural interests that would view introduction of *Cactoblastis* as beneficial to suppress *Opuntia* on rangelands, though its discovery in the Florida Keys, which are not noted for agriculture, suggests that this was not the means of arrival. But, in Florida, there are endangered *Opuntia* species. The interests of agriculture, horticulture, and conservation are here in conflict. Boat traffic between the Florida Keys and other islands gives adult moths a good possibility of hitchhiking. There is a minor possibility that adult moths flew directly from Cuba, perhaps aided by winds.

Some Philosophical Concerns About Insects and Insect Introduction in Florida

Although species of exotic vertebrates and plants have, for the most part, been **introduced** to Florida deliberately, adventive species of insects are predominantly **immigrants** (i.e., not deliberately introduced; see Frank & McCoy 1990 for a discussion of these terms; also see Frank & McCoy 1992, 1993, 1994). The introduced vertebrates and plants were brought to Florida because they were thought to possess desirable properties, and only later did they prove to be invasive and potentially detrimental to the native flora and fauna. The introduced insects also were brought to Florida because they were thought to possess desirable properties, principally in controlling pests. It is not clear that any of the insect species introduced to Florida for pest control have been detrimental to the native biota, although the potential for harm clearly is present (see Simberloff 1992, Simberloff & Stiling 1993). The potential for harm to rare insects outside the crop environment is an especially important, although underappreciated, consideration of classical biological control programs (Samways 1988, 1994).

The need to integrate conservation and pest control concerns raises some interesting philosophical—as well as practical—questions. The first has to do with insect conservation: Is too little attention paid to insect conservation (see New 1984, Samways

1994)? In Florida, the official lists of endangered and potentially endangered animal and plant (Wood 1993) taxa include 17 of fish (includes species, subspecies, and populations), 6 of amphibians, 27 of reptiles, 45 of birds, 43 of mammals, and 566 of plants. The lists also contain 85 invertebrate taxa, of which 47 are insects. Seven orders are represented among the listed insect taxa: Ephemeroptera (2 taxa), Odonata (4), Orthoptera (4), Coleoptera (19), Trichoptera (6), Lepidoptera (8), and Diptera (4). Within the two best-represented orders, 6 of the 8 lepidopteran taxa are butterflies, and 15 of the 19 coleopteran taxa are scarabs. One butterfly, Schaus' swallowtail, is listed as endangered by both the USFWS and the FGFWFC; the other 46 insect taxa are listed as C2 by USFWS, but are not listed at all by FGFWFC. The C2 listing offers no federal protection, and means only that USFWS encourages consideration of such taxa in environmental planning. Furthermore, the document created to allow governmental agencies in Florida to set conservation priorities in a reasonable way (Millsap et al. 1990) keys only on "fish and wildlife," and, thus, does not deal with invertebrates or plants. By implication, the omission of invertebrates, coupled with their relatively-poor representation in the official lists, suggests that persons who might be interested in studying rare invertebrates probably are not likely to obtain funding from the agencies who employ this document. Although the USFWS insists that insects are "wildlife," the FGFWFC apparently has not subscribed to this inclusive definition in the granting of funds through its Non-Game Wildlife Program (with the exception of Schaus' swallowtail). The advice to persons interested in insect conservation often is to apply to an agricultural agency for funding, even if the kinds of insects those persons wish to study have nothing to do with agriculture. Finally, the attempt to set conservation priorities in a reasonable, comparative way (Millsap et al. 1990), and thereby to avoid use of perception, politics, and other such criteria which typically affect governmental lists of taxa at risk (see McCoy & Mushinsky 1992), succeeds, as much as it does, only for vertebrates. Among insects, the few conservation efforts that are mounted are likely to be directed at the showy, popular taxa, such as butterflies and beetles (see Pyle et al. 1981, Samways 1994), rather than at the bland ("ugly" in some minds), obscure taxa, despite the fact that such taxa may be equally, or even more, threatened (see Samways 1994).

So, a case can be made that indeed too little attention is paid to insect conservation. We suggest that it is important at least to recognize the possibility that a very large and diverse group of organisms is being neglected. Insects currently suffer from a poor public image, although they have not always done so (Frank & McCoy 1991, Samways 1994). Unfortunately, some popular philosophical theories about nature reinforce this poor image. For instance, individualistic theories embraced by many animal-rights activists (e.g., Regan 1983, Singer 1985), apart from their failure to attach increased moral status to endangered taxa, paternalistically focus attention on creatures which are most like humans (see des Jardins 1993). So-called holistic philosophical theories about nature offer an alternative to individualistic theories—and to biocentric theories (e.g., Taylor 1986), as well (see des Jardins 1993). The commonly employed philosophical and ecological bases for these holistic theories seem to be weak, however (Peters 1991, Shrader-Frechette & McCoy 1993). Because of their numbers and diversity—and even their utilitarian values—insects are likely to fare well under a more holistic perspective of nature. And if so, then it follows that to employ this more holistic perspective, we must better understand the ecological roles insects play. A first step toward increased understanding in Florida is characterization of the habitats of very many more of the taxa indigenous to the state, especially those that are precinctive (Frank & McCoy 1995), a process that is well under way in other places, such as the Amazonian rain forest (T. Erwin pers. comm.).

A second philosophical and practical question involves movements of organisms. The question is: Are the risks of introductions of certain kinds of organisms, namely classical biological control agents, scrutinized too closely, relative to those of other kinds of organisms? To address the question, we must provide a little history.

Importers of insects have for years had to follow federal regulations required by USDA-APHIS-PPQ, USDA-APHIS-VS, and USPHS-CDC. These regulations were designed to ensure that insects imported into the USA should not become pests; that is, they were not likely to be phytophagous on commercially-important plants ("plant pests"), or parasites and/or vectors of diseases of farm animals ("animal pests"), or parasites and/or vectors of diseases of humans ("vectors"). By extension, the regulations were applied to phytophagous insects that were actual or potential biological control agents of weeds, so that such insects could be imported only to approved quarantine facilities, until further approval for release were issued. By further extension, under nebulous authority, the regulations also were applied to entomophagous insects imported for biological control purposes. We shall place the insects discussed in this paragraph in "category A."

The federal regulations applied to insects in category A never applied to many other insects that at least had the potential to become pests. Among these other insects are termites, cockroaches, pests of stored products (e.g., mealworms and crickets imported as fish bait), honey bees, silkworms, insects imported for "educational purposes" (e.g., certain mantids), and insects and other arthropods imported as "pets" (e.g., certain scorpions and tarantulas). Insects, such as exotic butterflies imported by hobbyists or insect zoos, might or might not have been considered "plant pests," but were not required to be held in quarantine facilities regardless. While agricultural inspectors at land-, sea-, and airports examined cargoes for "plant pests" and "animal pests," they more or less left other living arthropods alone. Further, agricultural inspectors had no jurisdiction over the business of USPHS-CDC—which did not have its own inspectors—so they were not required to report discovery of "vectors," such as mosquito larvae, among shipments of plants. Still further, although agricultural inspectors could deny entry to declared biological control agents without permit, they did not have jurisdiction over entomophagous insects, and were not required to report these either, so entomophagous insects could be imported by the public. In brief, there was little or nothing to prevent members of the public from importing all kinds of entomophagous and other insects—so long as they were not obvious "plant pests" or "animal pests"—and nothing to prevent these insects from being released into the environment. Put simply, a wide variety of living insects could be imported legally and released into the environment. Agriculture and horticulture were protected, which was the stated purpose of the law, but the natural environment was largely unprotected. We shall place the insects discussed in this paragraph in "category B."

Later, EPA was empowered to regulate entry of biological control agents. By federal inter-agency agreement, it was decided that USDA-APHIS was doing a good job of regulating entry of insect biological control agents, and the EPA had no need to duplicate the effort. But, the emphasis still was on regulation of insects in category A. The insects in category B, that had been ignored by USDA-APHIS, were now being ignored by EPA.

The Florida legislature, in 1993, finally saw that all sorts of insects and other terrestrial arthropods were entering Florida under various guises, not only from abroad, but also from other states of the USA. It decided that **all** living insects and other terrestrial arthropods that anyone wanted to import should be subject to evaluation and permitting by DPI-FDACS. The law that it enacted was, arguably, the first sensible attempt at regulating importation of living organisms in the country. In fact, it makes

the federal laws unnecessary and redundant, as far as importations into Florida are concerned. The Florida law should serve as a model for a revised federal law. Only if the federal law becomes as stringent as the Florida law, and covers inter-state shipment, should the Florida law be repealed.

Later still, USFWS, which has no inter-agency agreement with USDA-APHIS, decided that insects are wildlife and importers/exporters of insects must follow its wildlife regulations and the wildlife regulations that it attributes to countries of origin. Thus, for example, anyone collecting insects in Mexico has to buy a Mexican hunting permit (for $750) and hire a Mexican hunting guide, according to USFWS regulations. Such permits are difficult—nearly impossible—to obtain, and so all insects exported from Mexico, dead or alive, are currently illegal in the eyes of USFWS. Tens of millions of insect specimens in national, state, and private collections technically are illegal contraband, because they are not accompanied by wildlife permits. USFWS does not recognize Mexican collecting/export permits for insects issued by Mexican agricultural/scientific authorities, which are much easier to obtain. Although USFWS is rightly attempting to restrict trade in insect specimens belonging to endangered species (mainly butterflies), it is inadvertently causing a severe hindrance to biological control. This problem could be solved by federal inter-agency agreement.

Based on our historical account, we conclude that the risks of introduction of biological control agents are scrutinized much more closely than those of other kinds of insects. We would not suggest that as a consequence of this uneven treatment, monitoring of importation of biological control agents should be slackened. Indeed, there is need for classical biological control to become more predictive (see Samways 1994). Rather, we would suggest that monitoring of the importation of other kinds of insects needs to be tightened, if the realized and potential threat of "biological pollution" by insects is to be lessened. To lessen the threat, we submit the following four proposals. First, legal (under permit) and illegal (without permit) importation of "pet" insects and other terrestrial arthropods should cease. Penalties for attempted illegal importation will have to be made more obvious and more severe. Second, insects imported for educational and research purposes (by universities, schools, zoos, and other organizations) should be held under conditions as secure as those now required for initial importation of biological control agents. Third, importation of "ornamental" plants should cease, unless importations are limited to seed—to restrict hitchhiking insect pests—or unless all incoming shipments are fumigated with chemicals shown to have ovicidal activity or dipped in chemicals with ovicidal activity. Fourth, all incoming shipments containing wood or other vegetable matter, even if only as packing crates, should be fumigated with chemicals shown to have ovicidal activity. Importers of insects or vegetable matter will have to pay the costs of any necessary secure facilities or required chemical treatment. All ships and boats arriving at Florida docks will have to be fumigated at owners' expense. All road vehicles will have to be stopped at Florida's borders and the drivers cautioned about potential searches, and fumigation of plant materials. If these restrictions cannot be implemented, because of political and economic pressure, then importers should pay into a fund which would provide research costs for the biological control of organisms that become established in nature.

CONCLUSIONS

Many biologists still fail to comprehend the means of arrival of adventive (= "non-indigenous") organisms in Florida, and in the USA in general. It may be that almost all adventive vertebrates and plants are introduced. But, by following an assumption

that adventive insects likewise are introduced, they confuse purposeful introduction with all other means of arrival. We distinguish these other means of arrival as **immigration**, which we consider to include all the undocumented modes of arrival, including flight, walking, swimming, rafting, and hitchhiking in cargoes. It is **immigrant** species which form 95.7% of the adventive insects in Florida (Frank & McCoy 1995) — and some of them are important pests. The **introduced** species in Florida, in contrast, were imported and released under permit because they are potentially beneficial—all of them are biological control agents of pests. None of them has been implicated in any kind of environmental damage. We are concerned that well-meaning but uninformed biologists should not label "introduced" (= all non-indigenous; their definition) insects as necessarily a bad thing for the environment—when, in fact insects **introduced** (our definition) by humans may be the least risky way to save the environment from damage caused by other organisms, purposefully or inadvertently, brought to Florida by humans.

This Symposium

We have suggested that, in order to deal with biological pollution in a more even-handed way, greater attention needs to be paid to documentation of Florida's insect fauna and to philosophical and practical questions involved with insect introduction. The contributions to this symposium address these two subjects. J. H. Frank & E. D. McCoy (1995) offer, for the first time, estimates of the current size of the Florida insect fauna, the proportion of indigenous and adventive species and, within these categories, the proportion of precinctive, indigenous but not precinctive, and immigrant species. They use information from various experts coupled with knowledge from an earlier paper on number of introduced species, to derive these estimates. They then compare their estimates with similar ones derived for the insect fauna of Hawaii. Although Hawaii's immigrant insect problem is much worse than Florida's, Frank & McCoy (1995) find no reason to be complacent, because Florida's immigrant insect problem may be much worse than those of most of the other contiguous states.

Plants introduced for ornamentation and insects introduced for purposes other than biological control raise important questions about the efficacy of biological introductions in general. For these kinds of organisms, especially, the risks to the public could be great enough to outweigh any benefits of introduction that might accrue. Substantial attention should be paid to the potential risks of such introductions. D. Cathcart discusses the potential benefits of importing bromeliads: aesthetics; research on systematics, physiology, and culture methods; preservation of gene pools; and, perhaps, production of bromeliads to restock areas in their native lands where they have become extirpated or endangered. He also discusses the precautions taken by his firm to ensure that insects do not hitchhike into Florida on bromeliads. R. Boender discusses the potential benefits of importing butterflies, and derives a list very similar to Cathcart's: entertainment, education, research on production methods, production of living specimens for use by researchers, preservation of gene pools and, perhaps, production of butterflies to restock areas in their native lands where they have become extirpated or endangered. He also discusses the precautions taken by his butterfly farm and exhibition to ensure that butterflies do not escape and become established "plant pests."

Insects introduced as biological control agents have contributed some conspicuous successes in the struggle to reduce the effect of invasive adventive species in Florida. T. D. Center and co-workers illustrate the use of biological control to solve problems caused on public lands—including waterways—by introduced and immigrant species.

Problem species on public lands mainly are plants, but to a lesser extent, also include insects. Center and co-workers reiterate the important point that even though some members of the public may see classical biological control as contributing yet more adventive species to already burdensome numbers, classical biological control is an environmentally sound solution to the problem caused by some introduced and immigrant species.

Insect introduction for the purpose of biological control has a long history of government regulation in Florida. M. C. Thomas reflects the concerns of FDACS-DPI about immigrant and introduced insects. He points out that state laws now require importation permits for **all** arthropods and molluscs (no longer just for "plant pests" and biological control agents) from anywhere outside Florida. He warns of the significant potential danger to the environment from the kinds of arthropods and molluscs that the pet trade has been importing.

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