CARGO AIRCRAFT AS A PATHWAY FOR THE ENTRY OF NONINDIGENOUS PESTS INTO SOUTH FLORIDA

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ABSTRACT

Cargo aircraft arriving at Miami International Airport from foreign origins were randomly selected and inspected from September 1998 to August 1999 for the presence of live hitchhiking insects. An overall infestation (= approach) rate of 10.4% was found, with the rate for aircraft arriving from Central American countries noticeably greater at about 23%. Quarantine-significant taxa from 33 families in five orders were detected, with members of Lepidoptera and Coleoptera most frequently encountered. More than 40% of infested aircraft contained multiple insect taxa. No correlation was established between the presence of hitchhiking insects and the time of day (night vs. day) during which cargo was loaded at points of origin or the nature of cargo on board. Quarantine-significant organisms arrived in cargo aircraft during all months of the year. Significant seasonality (dry season vs. wet) was observed for pests on flights arriving from Central America, with separate peaks noted in May and October.

Key Words: aircraft, exotic pests, nonindigenous organisms, pathway, Florida

RESUMEN

Los aviones de carga arrivados al Aeropuerto Internacional de Miami de origen extranjero fueron seleccionados al azar para ser inspeccionados desde Septembre 1998 hasta Agosto 1999 para la presencia de insectos vivos introducidos al pais. Se encontró un grado de infestación (= abordamiento) total de 10.4%, con un grado notablemente mayor en aproximadamente 23% de los aviones procedentes de los paises Centroamericanos. Las clases de insectos (taxa) significativas para la cuarentena perteneciendo de 33 familias y cinco ordenes fueron detectados, con miembros de Lepidóptera y de Coleóptera fueron los más frecuentemente encontrados. Más del 40% de los aviones infestados tenían multiples clases de insectos. No fué establecida una correlación entre la presencia de los insectos en el avión y la hora del día (la noche vs. el día) cuando el cargamento fué cargado en los puntos de origen ó la naturaleza del cargamento en el avión. Los organismos significativos para la cuarentena llegaron en aviones de cargamento durante todos los meses del año. Las plagas observadas en las aviones variaron significativamente según la estación (la estación seca vs la estación lluviosa), con poblaciónes más altas durante mayo y octubre.

Preventing the entry and subsequent establishment of nonindigenous (= adventive *sensu* Wheeler & Hoebeke 2001) organisms into the United States has been one of the primary missions of the U.S. Department of Agriculture's Animal and Plant Health Inspection Service, Plant Protection and Quarantine (APHIS-PPQ). Pathways of entry that it actively monitors include passenger baggage, cargo, international mail, foreign garbage, and conveyances such as ships, trains, cars, trucks, and aircraft.

APHIS-PPQ has long been aware that aircraft have the potential to transport insects both internationally and domestically. For several decades, Agency officials issued annual springtime alerts for inspectors to monitor aircraft arriving from Panama and the Canal Zone for the presence of hitchhiking scarab beetles. Two scarab genera of primary interest were *Liogenys* (*L. macropelma* Bates, in particular) and *Geniates*. In addition, APHIS officials annually monitor U.S. airports in regions infested with the Japanese beetle, *Popillia japonica* Newman, to ensure that domestic aircraft do not transport this pest to non-infested areas.

Researchers also have been aware of the connection between aircraft and the dissemination of insect species from one region to another. Swain (1952) predicted more than a half century ago that aircraft would become a major distributor of insect pests. He reported that nearly 3000 species of insects from 293 families had already been detected traveling aboard aircraft. Also, he attributed the invasion of the Hawaiian Islands by the Oriental fruit fly to abandoned exclusionary precautions involving military aircraft from the Mariana Islands during World War II. Of the insects introduced into Guam during the 1980s, Schreiner (1991) concluded that four species of Noctuidae and several species of Coleoptera and Homoptera probably arrived as hitchhikers in the holds or cabin areas of aircraft. McGregor (1973) stated that many future accidental introductions of exotic insects into North America would likely occur via this pathway. Sailer (1978) argued for the creation of ecological barriers around areas of major foreign traffic, such as international airports, to contain introductions of nonindigenous insects.

Despite this awareness by government agencies and researchers, the literature contains few formalized studies that investigated aircraft as a pathway for insect introduction. Of these few studies, none focused on infestation rates (referred to as approach rates by regulatory officials) of foreign-arriving aircraft. In addition, none concentrated on hitchhiking insects of potential economic significance to agricultural crops, forests, and ornamentals. Most of the work instead has focused on insects of public health importance. Studies conducted in Australia (Russell et al. 1984; Davidson 1990), Japan (Otaga et al. 1974; Takahashi 1984), New Zealand (Laird 1951), the Philippines (Basio et al. 1970), Singapore (Goh et al. 1985), and the United States (Evans et al. 1963) spotlighted hitchhiking insects that vector human pathogens or parasitize livestock. Other researchers (Sullivan et al. 1958; Russell 1987) studied how well insects survive in various compartments of jet aircraft.

Airports in Florida, subtropical South Florida in particular, are primary arrival sites for cargo aircraft transporting large quantities of foreign-grown perishable products such as cut flowers, vegetables, fruits, and ornamental plants. From 1994 to 2000, the tonnage of perishable commodities imported into Florida by cargo aircraft slightly more than doubled (Klassen et al. 2002). Over this same period, the number of quarantine-significant pest detections resulting from inspection of these commodities increased 1.7-fold (Klassen et al. 2002). More than 19,000 cargo flights arrived at Miami International Airport in 2002 (APHIS-PPQ, unpublished); this number is projected to increase as consumption of perishable items throughout the U.S. increases.

Steady increases in cargo flight arrivals and tonnage of perishables into Florida will likely be accompanied by increased numbers of nonindigenous insect species that become established. Florida has a history of vulnerability to successful invasion by such organisms. For the period 1970-1989, about as many adventive arthropods annually became established in Florida as in all other areas of the continental United States combined (Frank & McCoy 1992). Only Hawaii exceeds Florida in the number of adventive arthropods that become established each year (Beardsley 1979). This vulnerability to invasion has affected the composition of the fauna of Florida over time. An estimated 15-25% of all major taxonomic groups in South Florida are considered to be nonindigenous, in stark contrast to 1.7% for other regions within the continental United States (Ewel 1986). About 1000 of the 12,500 arthropods in Florida, or about 8%, are nonindigenous (Frank & McCoy 1995).

Given the vulnerability of Florida to invasion by insects, ever-increasing arrivals of cargo aircraft into Florida, and a lack of knowledge about cargo aircraft as an entry pathway for adventive organisms of potential economic impact, APHIS-PPQ in Miami undertook a study to determine: (1) overall and regional approach rates for cargo aircraft arriving at Miami International Airport, (2) the number of insect taxa aboard cargo aircraft, (3) the taxonomic composition of intercepted organisms, (4) potential day/night differences in approach rates, (5) approach rate differences based on cargo type, and (6) seasonal differences in the number of organisms detected.

Materials and Methods

Sample Size and Selection

In 1996, approximately 23,000 cargo aircraft arrived in Miami, Florida, from foreign origins (APHIS-PPQ, unpublished), which equates to about 60 arrivals per day. To detect an infestation (= approach) rate as low as 1% with a 95% level of confidence, a sample size of 730 aircraft was selected, and two aircraft were randomly selected and inspected each day of the study period. The study was conducted over a 12-month period from 1 September 1998 to 31 August 1999. This duration would enable seasonal effects involving rainfall and temperature to be detected, at least for the most frequently sampled regions and countries.

To select samples, each day was divided into 96 quarter-hour increments. The increments were sequentially numbered with midnight to 12:14 AM being increment number one, 12:15 to 12:29 AM being increment number two, and so on. Daily, a random number table was used to select two numbers from one to 96 that corresponded to particular quarter-hour increments. The first foreign cargo aircraft scheduled to arrive during or after the selected increment was designated as a sample.

Sample Inspection Process

The regular workforce of approximately 150 APHIS-PPQ officers in Miami was specially trained and equipped to assist with this study. (Most APHIS-PPQ officers have subsequently been transferred into the newly created Department of Homeland Security, although duties relating to aircraft inspections remain unchanged.) When a sample aircraft arrived, the assigned officer immediately inspected the cockpit and galley areas for live hitchhiking organisms (i.e., insects, snails, slugs, and weed seeds). Unconsumed fresh fruits found in these areas were bagged in plastic to be examined later for commodity-associated insects and diseases. Flight crew members were asked to provide the exact time when the aircraft departed from the foreign airport from which it was arriving. The officer remained at the aircraft location throughout the cargo offloading process, during which time all surfaces of palletized cargo were inspected for hitchhiking organisms. When offloading was completed, the officer intensively examined the floors, walls, other surfaces, and air space within all cargo compartments for hitchhiking pests.

During and after the inspection, the officer recorded all pertinent information concerning the aircraft and the inspection on a specially designed data form to which were attached the cargo manifest and the U.S. Customs general declaration.

Identification of Specimens

All live specimens found associated with sampled aircraft were submitted to APHIS-PPQ local specialists for immediate identification. All determinations were made to the lowest taxon possible. When local specialists were unable to perform specific identifications, specimens were forwarded to national specialists located in Washington, DC, Beltsville, MD, Columbus, OH, and Miami, FL, depending on the type of organism intercepted. Specimens could not always be identified to the species or generic level because of the poor condition of material, lack of specialists or scientific knowledge for certain taxonomic groups, and taxonomic keys based on a single sex.

Following identification, specimens were categorized as either quarantine-significant (QS) or non-quarantine-significant (NQS). QS taxa are defined as species of plant-feeding insects, mites, or mollusks, plant-infecting pathogens, or weed seeds that are not known to occur, or are not widely distributed, in the United States. Specimens belonging to plant-feeding groups, but identified only to the family or generic level, are also placed in this category because they could potentially represent QS taxa. NQS taxa are species that are widely distributed in the United States and/or are categorized by APHIS-PPQ as not likely to pose a significant threat to U.S. agriculture, forests, and ornamentals.

We did not classify the relative risk levels of QS taxa. Instead, individual interceptions were simply grouped into one of the two categories outlined above, a practice that is widely used within APHIS-PPQ when making quarantine decisions.

Data Collection and Analysis

All data relating to the sampled aircraft were collected from specially designed data forms completed by the officers, or from official federal documents associated with the aircraft. Selected data were compiled into a local database. In addition, all data on QS taxa were recorded in the national Port Information Network (PIN) database which contains all pest interception reports since 1985. References to new records in this study imply that a given QS taxon did not appear in PIN in association with (1) aircraft as an entity, apart from any transported cargo, and/or (2) a particular U.S. port of entry, e.g., Miami.

Countries were grouped into one of the following regions for purposes of calculating regional approach rates: Central America, South America, West Indies, Europe, and Other. Trinidad was considered to be part of South America, not the West Indies, in keeping with other federal practices. Mexico was included among Central American countries. Canada and Taiwan were grouped in the artificial category “Other”.

A comparison of data for aircraft loaded during daylight hours versus those for aircraft loaded at night was made to determine if bright lights necessary for nighttime cargo operations attracted nocturnal fliers, thus increasing approach rates. The comparison was difficult because the precise time during which aircraft are loaded at the point of origin is not recorded by airline personnel. Aircraft logbooks, however, consistently reflect the time at which aircraft depart. Our experience at Miami International Airport has shown that commercial aircraft nearly always depart immediately after cargo loading is complete. Time of departure was therefore used as a close approximation of the time when cargo was loaded. Aircraft with departure times between 7:00 AM and 7:00 PM were considered to be loaded during daylight hours, while those departing between 7:00 PM and 7:00 AM were considered to be night-loaded. Efforts were focused on cargo aircraft arriving from Central America since approach rates from this region were substantially higher than those observed from any other. Departure times for seven aircraft from this region were not available. Temporal analyses also were performed on the Auchenorrhyncha, Noctuidae and Scarabaeidae found. These three groups were repeatedly intercepted during the study and are either primarily nocturnal or generally attracted to lights. Each was examined to determine if time of loading had any effect on their presence as hitchhikers.

To determine if certain types of cargo were more attractive to hitchhiking organisms, the commodities being transported were divided into two broad categories, regulated and non-regulated, with the approach rates of each examined. Regulated cargoes are agricultural in nature and are generally inspected on arrival by APHIS-PPQ. Plants or plant products make up the bulk of these items. Non-regulated cargoes are miscellaneous items not considered to be derived from agricultural sources.

Investigations into potential aspects of seasonality were restricted to Central America since aircraft arriving from that region experienced a far greater approach rate than did aircraft from any other region. Central America has essentially two seasons, wet and dry (Alfaro 2000). The onset of the wet season varies slightly from year to year but begins around May and lasts for approximately six months. For the purposes of our analyses, we considered the wet season to be from 1 May through 31 October, and the dry season to be from 1 November through 30 April. Aircraft were grouped into one these two categories and the approach rate for each was examined.

The *G*-test of independence (Sokal & Rohlf 1981) was used to determine if the presence of QS organisms in sampled cargo aircraft varied independently of or was correlated with (1) the time of departure from foreign origins, (2) the nature of the cargo loaded aboard and (3) the season of departure. For the time and season of departure, only the data pertaining to aircraft originating in Central America were included in the *G*-test. Regarding the nature of cargo, sampled aircraft from all geographic regions were included. In all cases, *G* values were adjusted by Williams' correction for 2 × 2 contingency tables (Sokal & Rohlf 1981) and then compared with the critical value of chi square at the 5% significance level and 1 degree of freedom.

Results and Discussion

Approach Rates by Region and Country

Aircraft were sampled from 38 countries during the study, with QS organisms detected in aircraft arriving from 17 of these. The overall pest approach rate for foreign cargo aircraft arriving at Miami International Airport was 10.4% (Table 1). The approach rate for Central America (23.2%) was substantially greater than rates observed for any other region. Aircraft from all sampled countries in Central America contained QS organisms. Approach rates for individual countries within Central America varied slightly, with Costa Rica, El Salvador, Guatemala, and Honduras all greater than 23%. Mexico and Panama were approximately 10 percentage points lower. The approach rate for Nicaragua was substantially greater (50%), although this figure might be less reliable than others for the region due to the comparatively smaller sample size. The mean approach rate of more than 23% was at least four times that seen from any other region.

Approach rates for South American countries ranged from 0 to 15.9%, with a mean of 5.8%. Aircraft from six of the ten sampled countries contained QS pests. Small sample sizes for Argentina (7), Bolivia (4), and Uruguay (1) produced questionable approach rates for these countries. Ecuador had the highest approach rate for the region, followed by Trinidad. Rates observed for Peru and Colombia were noticeably lower. The approach rate for Argentina was also quite high, although the sample size (7) was relatively small. More aircraft were sampled from Colombia (155) than from any other country during the study, reflecting the tremendous volume of goods it exports to Miami. Most of those aircraft transported perishable cut flowers that could be attractive to phytophagous pests but, despite that, the observed approach rate almost equaled the mean rate for the region. Large numbers of aircraft from Brazil, Chile, and Venezuela were sampled, but very few were infested.

Approach rates for countries within the West Indies also varied considerably, ranging from 0 to 18%. Infested aircraft originated from just three countries in the region—Jamaica, Haiti, and the Dominican Republic. The approach rate for Haiti (18%) was more than twice that of any other country in the region, albeit from a comparatively small sample size of 11. In contrast, Bahamas and the Dominican Republic, the two countries in the region with the largest number of sampled aircraft, had lesser approach rates of 0 and 2.9%, respectively.

We made no inferences about approach rates for other regions because sample sizes were usually small. The lone infested aircraft from France can be called into question. The scarab beetle found on board belonged to a genus (*Dyscinetus*) known only from the Western Hemisphere (Endrödi 1985). More likely, this insect actually entered the aircraft during a fueling stopover in Canada. In general, more data are necessary to better understand the risks associated with cargo aircraft from these areas.

Diversity of Intercepted Taxa

Various QS organisms were intercepted from infested aircraft samples. In total, 151 insects from 33 families in five orders were represented, along with one plant pathogen (citrus canker in aircraft stores from Argentina) (Table 2). All insect specimens were adults except two. A larva of *Crocidosema aporema* (Walsingham) was found in the emptied hold of an aircraft from Guatemala and likely originated from boxes of beans on board. In the second case, a tettigoniid nymph was found aboard an aircraft transporting fruits and live plants from Costa Rica.

Lepidoptera comprised the largest single component of captured specimens, followed closely by Coleoptera (Fig. 1). These findings generally agree with those of Frank & McCoy (1992), who noted that the two most numerous orders of nonindigenous organisms reported new to Florida since 1971 were Lepidoptera and Coleoptera. Conspicuous by their absence were interceptions

TABLE 1. APPROACH RATES BY COUNTRY AND REGION FOR CARGO AIRCRAFT ARRIVING AT MIAMI INTERNATIONAL AIRPORT, 1 SEP. 1998-31 AUG. 1999.

	Aircraft sampled (n)	Aircraft infested (x)	Approach rate (x/n)100 (%)
Central America			
Costa Rica	44	12	27.3
El Salvador	17	4	23.5
Guatemala	44	12	27.3
Honduras	33	8	24.2
Mexico	33	4	12.1
Nicaragua	8	4	50.0
Panama	28	4	14.3
Region	207	48	23.2
South America			
Argentina	7	1	14.3
Bolivia	4	0	—
Brazil	29	0	—
Chile	45	0	—
Colombia	155	8	5.2
Ecuador	44	7	15.9
Peru	16	1	6.3
Trinidad	17	2	11.8
Uruguay	1	0	—
Venezuela	28	1	3.6
Region	346	20	5.8
West Indies			
Antigua	2	0	—
Aruba	1	0	—
Bahamas	42	0	—
Barbados	1	0	—
Cayman Is.	3	0	—
Cuba	1	0	—
Dominica	2	0	—
Dominican Republic	35	1	2.9
Grenada	3	0	—
Haiti	11	2	18.2
Jamaica	12	1	8.3
St. Kitts	4	0	—
St. Lucia	3	0	—
St. Vincent	1	0	—
Turks & Caicos	1	0	—
Region	122	4	3.3
Europe			
France	4	1*	25.0
Luxembourg	4	0	—
Netherlands	10	0	—
Spain	5	0	—
Region	23	1	4.3
Other			
Canada	2	0	—
Taiwan	3	0	—
Overall	703	73	10.4

*Origin questionable

TABLE 2. QUARANTINE-SIGNIFICANT ORGANISMS INTERCEPTED IN FOREIGN CARGO AIRCRAFT ARRIVING AT MIAMI INTERNATIONAL AIRPORT, 1 SEP. 1998-31 AUG. 1999.

Organism	Origin	Frequency
COLEOPTERA		
Chrysomelidae		
Alticinae, species	Mexico	1
Acalymma sp.[a,b]	Ecuador	1
	Guatemala	1
Altica sp.[a,b]	El Salvador	1
Amphelasma sp.[a,b,c]	Honduras	1
Colaspis sp.	El Salvador	1
	Honduras	2
Epitrix sp.[a,b]	El Salvador	1
Exora encaustica (Germar)[a,b,c]	El Salvador	1
Longitarsus sp.[a]	Ecuador	1
Malacorhinus irregularis (Jacoby)[a,b,c]	El Salvador	1
Metachroma sp.[a]	Costa Rica	1
Rhabdopterus sp.[a]	Costa Rica	1
Typophorus sp.[a]	El Salvador	1
Curculionidae		
Curculionidae, species	El Salvador	1
Brachycerinae, species	El Salvador	1
Cleogonus sp.[a,b]	El Salvador	1
Conotrachelus sp.[a]	El Salvador	1
Elateridae		
Conoderus pictus (Candeze)[a,b]	El Salvador	1
Conoderus rodriguezi Candeze	Costa Rica	1
	Guatemala	1
Scarabaeidae		
Anomala sp.	Costa Rica	2
	Guatemala	1
	Honduras	1
	Nicaragua	1
	Trinidad	1
Cyclocephala sp.	Ecuador	1
	El Salvador	1
	Honduras	1
	Panama	1
Diplotaxis sp.[a]	Mexico	1
Dyscinetus sp.	France (?)	1
Euetheola bidentata Burmeister[a,b,c]	El Salvador	1
Liogenys quadridens (Fabricius)	Ecuador	1
Liogenys sp.	Colombia	1
	Ecuador	1
Manopus sp.[a]	Colombia	1
Phyllophaga sp.	Colombia	1
	Guatemala	2
Tomarus sp.	El Salvador	1
	Guatemala	2
	Trinidad	1

[a]New find in Miami aircraft.
[b]New find in aircraft nationwide.
[c]New Miami record, all sources.
[d]New U.S. record, all sources.
[e]Immature stage.

TABLE 2. (CONTINUED) QUARANTINE-SIGNIFICANT ORGANISMS INTERCEPTED IN FOREIGN CARGO AIRCRAFT ARRIVING AT MIAMI INTERNATIONAL AIRPORT, 1 SEP. 1998-31 AUG. 1999.

Organism	Origin	Frequency
Tenebrionidae		
Blapstinus sp.	Costa Rica	1
	Trinidad	1
HEMIPTERA: Auchenorrhyncha		
Auchenorrhyncha, species	Costa Rica	1
Cercopidae		
Prosapia sp.[a,b,c]	Costa Rica	1
	El Salvador	1
Cicadellidae		
Cicadellidae, species	Honduras	2
Typhlocybinae, species	Mexico	1
Dikraneurini, species	Panama	1
Chlorotettix sp.[a,b,c,d]	Honduras	1
Exitianus sp.[a,b,c,d]	Honduras	1
Graphocephala sp.[a,b,c]	Ecuador	1
Haldorus sp.[a,b,c,d]	Haiti	1
Tagosodes sp.[a,b,c,d]	El Salvador	2
Cixiidae		
Cixiidae, species	Mexico	1
Pintalia sp.[a,b,c]	Honduras	1
Nogodinidae		
Bladina vexans Kramer[a,b,c,d]	Colombia	1
HEMIPTERA: Heteroptera		
Cydnidae		
Cydnidae, species	Guatemala	1
Lygaeidae		
Nysius sp.[a]	Nicaragua	1
Miridae		
Phylinae, species	Ecuador	1
Reuteroscopus sp.[a,b]	Mexico	1
Sixeonotus sp.[a,b]	El Salvador	1
Tropidosteptes chapingoensis Carvalho & Rosas[a,b,c,d]	Colombia	1
Tropidosteptes sp.	Guatemala	1
Pentatomidae		
Berecynthus hastator (Fabricius)[a]	El Salvador	1
Rhopalidae		
Jadera sp.[a]	Costa Rica	1
Rhyparochromidae		
Rhyparochromidae, species	El Salvador	1
Prytanes sp.	Guatemala	1
ISOPTERA		
Kalotermitidae		
Cryptotermes sp.[a,b]	Honduras	1

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Organism	Origin	Frequency
LEPIDOPTERA		
Arctiidae		
Arctiidae, species	Colombia	1
Empyreuma sp.[a,b,c,d]	Dominican Republic	1
Crambidae		
Crambidae, species	Costa Rica	2
	Nicaragua	1
Elachistidae		
Elachistidae, species	Costa Rica	1
Gelechioidea		
Gelechioidea, species	Dominican Republic	1
Gelechiidae, species	Guatemala	1
Geometridae		
Geometridae, species	Costa Rica	4
	Ecuador	1
	Guatemala	3
	Nicaragua	1
	Panama	1
Eupethecia sp.[a,b]	Guatemala	1
Gracillariidae		
Phyllocnistis sp.[a,b,c]	Colombia	1
Noctuidae		
Noctuidae, species	Costa Rica	5
	Guatemala	3
	Haiti	1
	Honduras	2
	Mexico	1
	Nicaragua	5
	Panama	1
Catocalinae, species	Costa Rica	1
	Mexico	1
Copitarsia sp.	Colombia	1
Elaphria sp.	Costa Rica	1
Eulepidotis mabis Guenée[a,b,c,d]	Costa Rica	1
Ophisma sp.[a,b,c,d]	Nicaragua	1
Pararcte schneideriana (Stoll)[a,b,c,d]	Ecuador	1
Phalaenophana fadusalis Walker[a,b,c,d]	Costa Rica	1
Notodontidae		
Notodontidae, species	Costa Rica	1
Oecophoridae		
Stenomatinae, species	Costa Rica	1
Pyraloidea		
Pyraloidea, species	Guatemala	1
Pyralidae, species	El Salvador	2
	Peru	1

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TABLE 2. (CONTINUED) QUARANTINE-SIGNIFICANT ORGANISMS INTERCEPTED IN FOREIGN CARGO AIRCRAFT ARRIVING AT MIAMI INTERNATIONAL AIRPORT, 1 SEP. 1998-31 AUG. 1999.

Organism	Origin	Frequency
Sphingidae		
Sphingidae, species	Venezuela	1
Tineidae		
Acrolophinae, species	Colombia	1
Tortricidae		
Crocidosema aporema (Walsingham)[a,b,e]	Guatemala	1
ORTHOPTERA		
Gryllidae		
Gryllidae, species	Costa Rica	1
Allonemobius sp.[a,b]	Honduras	1
Gryllus capitatus Saussure	Ecuador	1
Gryllus sp.	Colombia	1
	Costa Rica	3
	Guatemala	2
	Honduras	3
	Jamaica	1
Tetrigidae		
Tettigidea sp.[a,b,c,d]	El Salvador	1
Tettigoniidae		
Tettigoniidae, species	Costa Rica[e]	1
	Honduras	1
Bucrates capitatus (De Geer)	Colombia	1
Conocephalus sp.	Honduras	1
Neoconocephalus punctipes (Redtenbacher)[a,b,c,d]	El Salvador	1
PLANT PATHOGEN		
Xanthomonas axonopodis Starr & Garces pv. *citri* (Hasse) Dye	Argentina	1

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[c]New Miami record, all sources.
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[e]Immature stage.

of Diptera and Hymenoptera. Members of these orders might be comparatively less attracted to light, QS groups such as leafminers and gall midges tend to be difficult to detect due to their small size, and relatively few QS taxa occur in these orders.

A sizable number of organisms intercepted during the study represented new records for APHIS-PPQ. These are denoted with superscripts in the list of taxa (Table 2). Of the 151 pests identified from infested aircraft, 32 (21%) belonged to taxa that had not previously been intercepted in cargo or passenger aircraft at U.S. ports of entry. Moreover, 13 (9%) of them had never been intercepted in conjunction with any pathway of entry.

Pests Per Infested Aircraft

Officers intercepted 151 QS organisms from the 73 infested aircraft. Some of these aircraft contained multiple organisms. The data indicate an inverse curvilinear relationship between the number of infested aircraft and the number of QS taxa per infested aircraft (Fig. 2). Accordingly, 59% of the infested aircraft had only one QS taxon, while 41% contained more than one, including one aircraft with 18. No other aircraft had more than seven QS pests.

Some infested aircraft harbored multiple individuals of the same taxon. For example, one aircraft sample contained a male and female of *Tomarus* (Coleoptera: Scarabaeidae). In such situations, the risk of establishment would presumably increase due to the presence of potential mating pairs.

Diurnal Patterns

Approach rates for all insect groups combined were not significantly different (*G*-test for indepen-

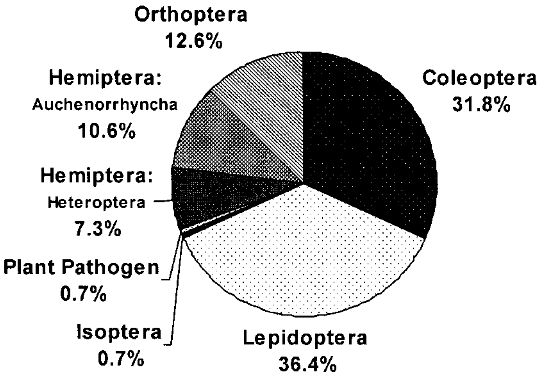

Fig. 1. Relative proportions of quarantine-significant taxa captured in foreign cargo aircraft arriving at Miami International Airport, 1 Sep. 1998-31 Aug. 1999.

dence; $p > 0.05$) for day versus night loading (Table 3). This apparent lack of correlation between time of loading and the presence of QS organisms suggests that APHIS-PPQ should continue to monitor cargo aircraft throughout the day.

Approach rates for the three primarily nocturnal groups also were not significantly different

TABLE 3. NUMBERS OF INFESTED CARGO AIRCRAFT FROM CENTRAL AMERICA: CORRELATION OF DEPARTURE TIME AND APPROACH RATE AT MIAMI INTERNATIONAL AIRPORT.[A]

Departure Time	Infested	Not Infested	Approach Rate
Day	14	62	18.4%
Night	35	89	28.2%

[a]G_{adj} of 2.488 not significant at $X^2_{0.05(1)}$.

(G-test for independence; $p > 0.05$) for day versus night loading (Table 4). The daylight condition during which loading took place was independent of Noctuidae, Scarabaeidae, and Auchenorrhyncha later being found aboard the aircraft. These results are somewhat surprising because these groups are generally attracted to lights. In explanation, some actual loading times might have differed substantially from recorded departure times. Also, some nocturnal hitchhikers might have entered aircraft during nighttime loading operations and subsequently made several round trips before being detected and incorrectly associated with day-loaded aircraft.

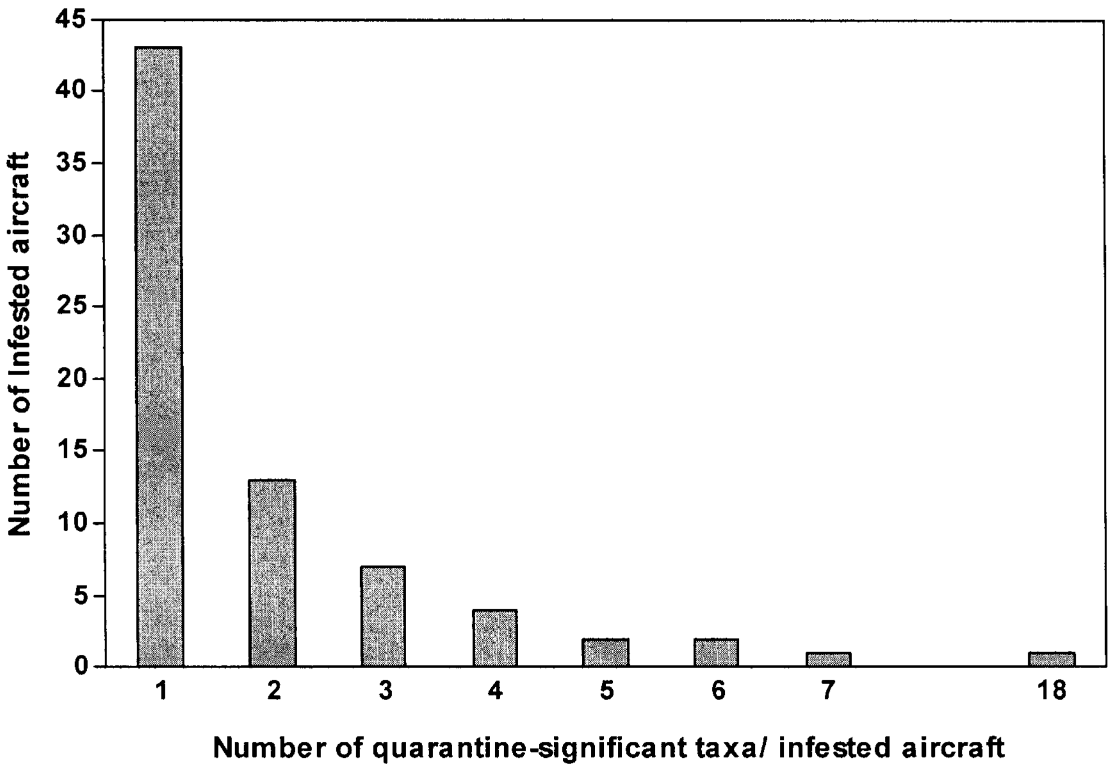

Fig. 2. Numbers of quarantine-significant taxa found aboard infested foreign cargo aircraft arriving at Miami International Airport, 1 Sep. 1998-31 Aug. 1999.

TABLE 4. NUMBERS OF CENTRAL AMERICAN CARGO AIRCRAFT INFESTED WITH NOCTUIDAE, SCARABAEIDAE AND AUCHENORRHYNCHA: CORRELATION OF DEPARTURE TIME AND APPROACH RATE AT MIAMI INTERNATIONAL AIRPORT.

Pest	Departure Time	Infested	Not Infested	Approach Rate
Noctuidae[a]	Day	5	71	6.6%
	Night	9	115	7.3%
Scarabaeidae[b]	Day	5	71	6.6%
	Night	4	120	3.2%
Auchenorrhyncha[c]	Day	3	73	3.9%
	Night	6	118	4.8%

[a]G_{adj} of 0.029 not significant at $X^2_{.05(1)}$.
[b]G_{adj} of 1.121 not significant at $X^2_{.05(1)}$.
[c]G_{adj} of 0.085 not significant at $X^2_{.05(1)}$.

Nature of Cargo

Demonstrating that higher approach rates result when cargo aircraft transport particular types of cargo might enable APHIS-PPQ managers to assign greater priority to inspection of those aircraft. Analysis of the data (Table 5), however, showed that approach rates for cargo aircraft were not dependent on whether regulated or non-regulated cargo was being transported (*G*-test for independence; $p > 0.05$). These results point to the need to inspect all foreign cargo aircraft arriving at Miami International Airport, regardless of the type of cargo being transported. Despite these results, though, it is conceivable that particular commodities, regulated and non-regulated alike, might serve to attract specific kinds of hitchhiking pests both before and during the cargo aircraft loading process. We note that 65% of the cargo aircraft sampled contained regulated agricultural material.

Seasonality Patterns

Monthly approach rates for aircraft from all origins were consistently greater in the spring and summer, with additional isolated peaks of 10% or greater in October and December (Fig. 3). QS organisms arrived at Miami International Airport via foreign cargo aircraft during all months of the year.

A pattern of seasonality emerged for Central America, but not for other regions. The infestation pattern for Central America (Fig. 4) resembled that for all regions combined (Fig. 3). Distinct peaks occurred in October and May, with the infestation percentage from April through August remaining at a generally high level. Unlike the pattern for all regions, however, the peak in October was as great as that in May. Approach rates for cargo aircraft arriving from Central America were significantly greater during the wet season there (about 29% from May through October) than during the dry season (about 16% from November through April) (*G*-test for independence; $p < 0.05$) (Table 6). Despite this seasonal difference, rates during the dry season were not low enough, in our opinion, to warrant deployment of personnel away from this pathway. Only in September and November did the percentage of infestation fall below 10 (Fig. 4). Additionally, there were two distinct peaks in January and April.

The pattern of total numbers of QS organisms per month (Fig. 5) largely resembled that for the percentage of infested aircraft per month (Fig. 3). The results for June, however, differed markedly. The percentage of infested aircraft for June was only moderate (Fig. 3), but the number of pests was exceptionally large (Fig. 5). This difference is attributable to an unusually large number of intercepted organisms (18) aboard a single aircraft from El Salvador (see Fig. 2).

We recognize that oceanographic and atmospheric factors, combined with latitude, influence when the wet and dry seasons begin and end annually in Central America (Alfaro 2000). Given these, it would be beneficial to gather multiple years of data for this region to improve understanding of any seasonality patterns. To obtain a similar understanding for the West Indies, much greater numbers of cargo aircraft would have to be sampled annually from a larger number of island countries. It might be more difficult to eluci-

TABLE 5. NUMBERS OF INFESTED CARGO AIRCRAFT FROM ALL ORIGINS: CORRELATION OF CARGO TYPE AND APPROACH RATE AT MIAMI INTERNATIONAL AIRPORT.[A,B]

Type	Infested	Not Infested	Approach Rate
Regulated	51	397	12.8%
Non-regulated	22	217	10.1%

[a]16 samples were either empty or contained indeterminable cargo.
[b]G_{adj} of 0.951 not significant at $X^2_{.05(1)}$.

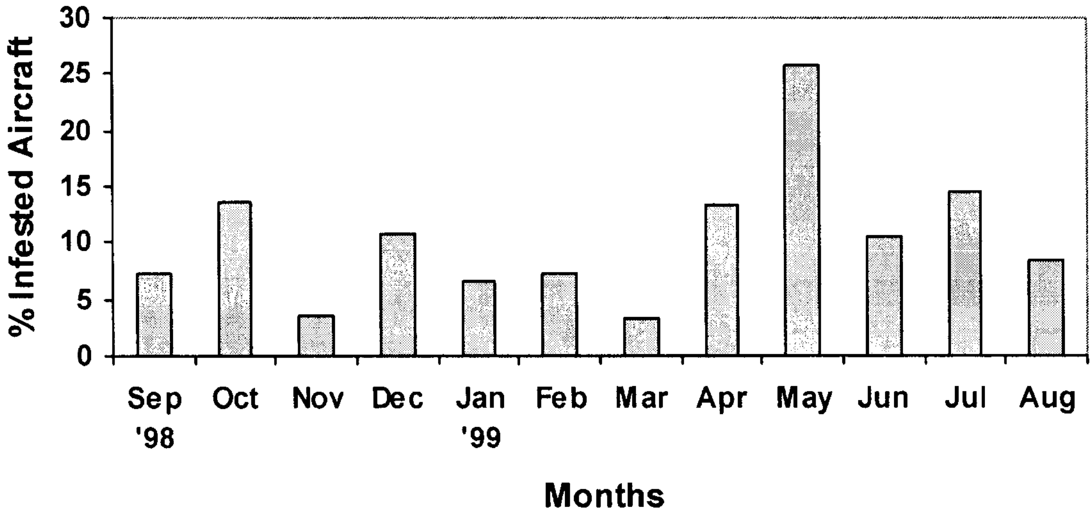

Fig. 3. Percent infested foreign cargo aircraft arriving from all origins at Miami International Airport, 1 Sep. 1998-31 Aug. 1999.

date seasonal patterns for South America due to its wide spectrum of topography, vegetation, latitudes, and bodies of water.

CONCLUSIONS

Our study demonstrated an overall pest infestation rate of 10.4% for foreign-arriving cargo aircraft at Miami International Airport. Cargo aircraft arriving from Central America had a much greater infestation rate of about 23%. In other words, almost one in four cargo aircraft arriving from Central American countries harbored live, nonindigenous organisms of potential economic impact to U.S. agriculture, forests, and ornamentals. Cargo aircraft arriving from these countries represent a potentially significant pathway for the introduction of adventive insects into South Florida. During the study, QS organisms arrived every month of the year, although peaks seemed to emerge in the fall and spring. The diversity of taxa encountered was substantial, with intercepted QS insects representing 33 families in five orders. Members of the Lepidoptera and

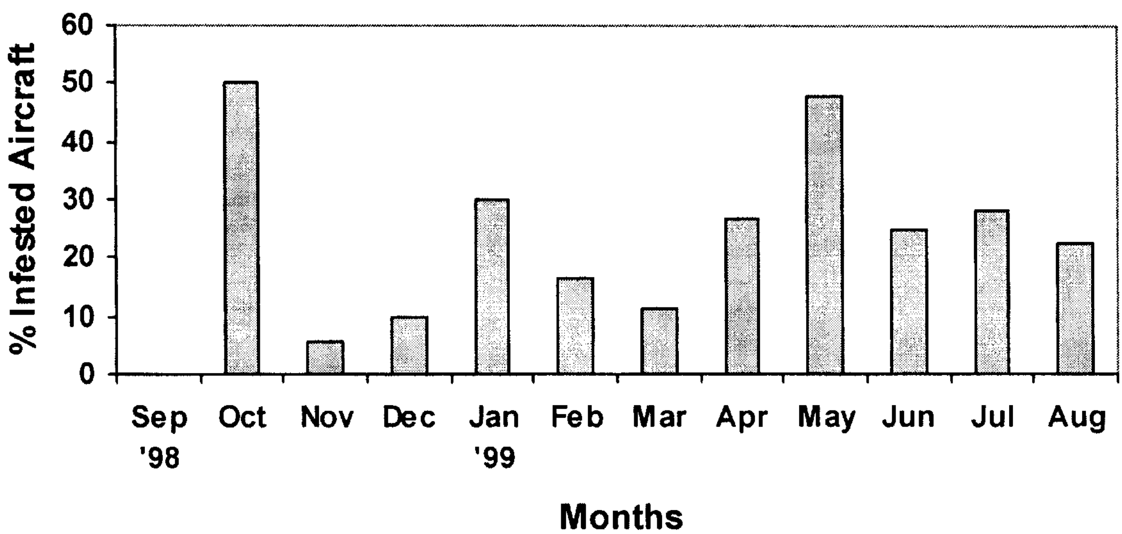

Fig. 4. Percent infested foreign cargo aircraft arriving from Central America at Miami International Airport, 1 Sep. 1998-31 Aug. 1999.

TABLE 6. NUMBERS OF INFESTED CARGO AIRCRAFT FROM CENTRAL AMERICA: CORRELATION OF SEASON OF DEPARTURE AND APPROACH RATE AT MIAMI INTERNATIONAL AIRPORT.[A]

Season	Infested	Not infested	Approach rate
Wet	34	84	28.9%
Dry	14	75	15.7%

[A]G_{adj} of 4.996 significant at $X^2_{.05(1)}$.

Coleoptera were most prevalent. Time of cargo loading and the types of cargo on board had no bearing on whether a particular aircraft contained QS organisms.

How to reduce the risks associated with this potential threat is the next question facing APHIS-PPQ managers. In recent years, calls for the formulation of offshore risk mitigation strategies have arisen within the regulatory and scientific communities of the United States (National Plant Board 1999, Shannon 1999, Klassen et al. 2002). Components of these strategies concerning commercial shipments have existed for decades and include pre-clearance programs, pest-free zones, cold treatments, and hot water treatments (Klassen et al. 2002).

Applied to cargo aircraft, such strategies might include one or more of the following for particular regions, countries, or even specific airports judged to be high-risk for hitchhiking insects: (1) periodically applying residual pesticides to the walls, floor, and ceiling of cargo holds; (2) placing insecticide-impregnated baits throughout the holds; (3) deploying sodium vapor lamps around aircraft during night loading so that fewer insects are attracted (Naumann & McLachlan 1999); (4) removing vegetation serving as potential pest reservoirs within a certain radius of cargo aircraft loading sites; (5) using black lights in vegetative areas away from aircraft to capture moths, beetles and other nocturnal fliers; (6) using compressed air to clean out cargo holds prior to loading; and (7) installing overlapping flexible plastic flaps in cargo doorways to impede the entry and exit of hitchhiking pests.

Additional surveys of cargo aircraft from countries and regions not adequately sampled in this study would provide useful information that could be incorporated into an overall strategy for mitigating the risks associated with this pathway. Expanding the present study to include passenger and private aircraft would provide additional information that APHIS-PPQ managers could use to formulate improved pest exclusion practices.

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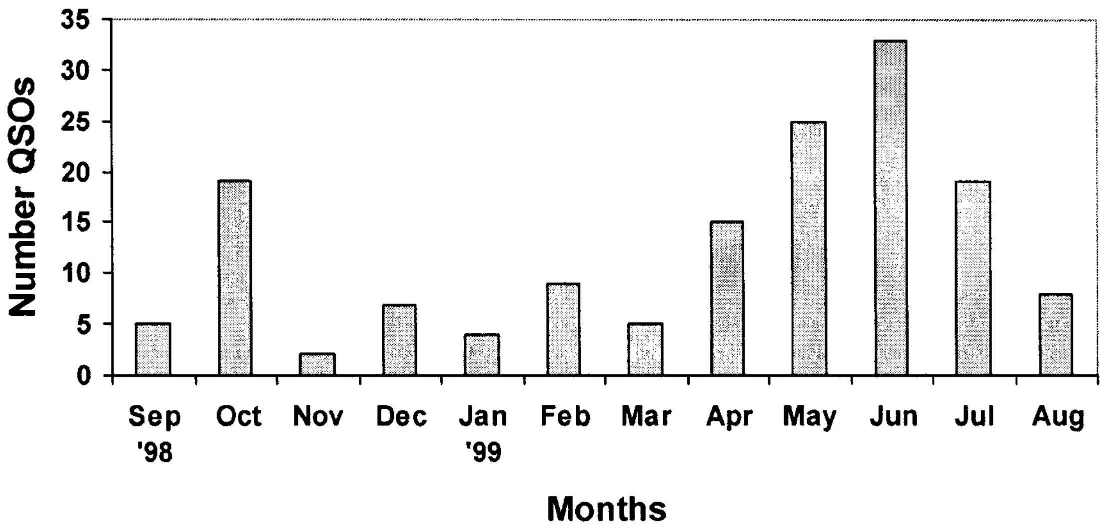

Fig. 5. Number of quarantine-significant organisms (QSOs) intercepted in foreign cargo aircraft arriving at Miami International Airport, 1 Sep. 1998-31 Aug. 1999.

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References Cited

ALFARO, E. J. 2000. Some characteristics of the precipitation annual cycle in Central America and their relationships with its surrounding tropical oceans. Top. Meteor. Oceanog. 7(2): 99-115.

BASIO, R. G., M. J. PRUDENCIO, AND I. E. CHANCO. 1970. Notes on the aerial transportation of mosquitoes and other insects at the Manila International Airport. Philippine Entomologist 1 (5): 407-408.

BEARDSLEY, J. W. 1979. New immigrant insects in Hawaii 1962 through 1976. Proceedings of the Hawaiian Entomological Society 23: 35-44.

DAVIDSON, S. 1990. Screw-worm stowaways—assessing the risk. Rural Research 146: 29-31.

ENDRÖDI, S. 1985. The Dynastinae of the World. Dr. W. Junk Publishers, Dordrecht, Netherlands. 800 pp.

EVANS, B. R., C. R. JOYCE, AND J. E. PORTER. 1963. Mosquitoes and other arthropods found in baggage compartments of international aircraft. Mosquito News 23: 9-12.

EWEL, J. J. 1986. Invasibility: lessons from South Florida, pp. 214-230. *In* H. A. Mooney and J. A. Drake (eds.). Ecology of Invasions of North America and Hawaii. Springer-Verlag, New York.

FRANK, J. H., AND E. D. MCCOY. 1992. The immigration of insects to Florida, with a tabulation of records published since 1970. Florida Entomologist 75: 1-28.

FRANK, J. H., AND E. D. MCCOY. 1995. Invasive adventive insects and other organisms in Florida. Florida Entomologist 78: 1-15.

GOH, K. T., S. K. NG, AND S. KUMARAPATHY. 1985. Disease-bearing insects brought in by international aircraft into Singapore. Southeast Asian J. Trop. Medicine and Public Health 16 (1): 49-53.

KLASSEN, W., C. F. BRODEL, AND D. A. FIESELMANN. 2002. Exotic pests of plants: current and future threats to horticultural production and trade in Florida and the Caribbean Basin. Micronesica Suppl. 6: 5-27.

LAIRD, M. 1951. The accidental carriage of insects on board aircraft. J. Royal Aeronautical Soc. 55: 735-743.

MCGREGOR, R. C. 1973. The emigrant pests: a report to Dr. Francis J. Mulhern, Administrator, Animal and Plant Health Inspection Service, Hyattsville, MD.

NATIONAL PLANT BOARD. 1999. Safeguarding American Plant Resources: A Stakeholder Review of the APHIS-PPQ Safeguarding System. APHIS, USDA, Washington, DC. 133 pp.

NAUMANN, I. D., AND K. MCLACHLAN. 1999. Aircraft disinsection, unpublished report, Australian Quarantine and Inspection Service. 125 pp.

OTAGA, K., I. TANAKA, Y. ITO, AND S. MORII. 1974. Survey of the medically important insects carried by international aircraft to Tokyo International Airport. Japanese J. Sanitary Zool. 25: 177-184.

RUSSELL, R. C. 1987. Survival of insects in the wheel bays of a Boeing 747B aircraft on flights between tropical and temperate airports. Bull. World Health Organization 65(5): 659-662.

RUSSELL, R. C., N. RAJAPAKSA, P. I. WHELAN, AND W. A. LANGSFORD. 1984. Mosquito and other insect introductions to Australia aboard international aircraft, and the monitoring of disinsection procedures, pp. 109-142. *In* M. Laird (ed.). Commerce and the Spread of Pests and Disease Vectors. Praeger, New York.

SAILER, R. I. 1978. Our immigrant fauna. Bulletin Entomol. Soc. of America 23: 3-11.

SCHREINER, I. H. 1991. Sources of new insects established on Guam in the post World War II period. Micronesica Suppl. 3: 5-13.

SHANNON, M. 1999. Challenges in safeguarding Florida and the U.S. against invasive pests, pp. 11-13. *In* W. Klassen (Chair). Mitigating the effects of exotic pests on trade and agriculture, Part A. The Caribbean. Proceedings of T-STAR Workshop-X, 16-18 June, 1999, Homestead, Florida. Cooperative State Research, Education, and Extension Service, USDA.

SOKAL, R. R., AND F. J. ROHLF. 1981. Biometry, 2nd ed. V. H. Freeman and Co., San Francisco. 859 pp.

SULLIVAN, W. N., F. R. DU CHANOIS, AND D. L. HAYDEN. 1958. Insect survival in jet aircraft. J. Econ. Entomol. 51(2): 239-241.

SWAIN, R. B. 1952. How insects gain entry, pp. 350-355. *In* F. C. Bishop (Chairman) et al. (eds.). Insects: the Yearbook of Agriculture, 1952. U.S. Government Printing Office, Washington, D.C.

TAKAHASHI, S. 1984. Survey on accidental introductions of insects entering Japan via aircraft, pp. 65-80. *In* M. Laird (ed.). Commerce and the Spread of Pests and Disease Vectors. Praeger, New York.

WHEELER, A. G., JR., AND E. R. HOEBEKE. 2001. A history of adventive insects in North America: their pathways of entry and programs for their detection, pp. 3-15. *In* Detecting and monitoring invasive species. Proceedings of the Plant Health Conference 2000: Raleigh, North Carolina. USDA, APHIS, PPQ, Center for Plant Health Science and Technology, Raleigh, NC.