Airline Baggage as a Pathway for Alien Insect Species Invading the United States

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ABSTRACT: Invasions by non-indigenous species are a problem of increasing magnitude and threaten the stability of the world's ecosystems and economies. Despite the enormity of this problem, relatively little is known about the importance of various invasion pathways. Using historical records of interceptions of alien insects in air passenger baggage by USDA inspectors, we characterize baggage as an invasion pathway. The most commonly infested commodity intercepted by inspectors was fruit (mainly tropical fruits), and the most commonly intercepted insects were Homoptera and Diptera. Numbers of interceptions from passengers originating in various countries were positively related to the volume of air traffic from that country and negatively associated with the gross national product of the country. In a more detailed case history, we used port inspection data to characterize baggage as a pathway for entry of the Mediterranean fruit fly, *Ceratitis capitata* (Wiedemann). Our analysis indicated that contrary to an earlier report, this insect has arrived at a sustained level in Los Angeles (and elsewhere); and these regulatory incidents can be used to explain the repeated detection of the species in California in years following eradication campaigns.

Biological invasions represent one of the most serious contemporary threats to ecosystem and economic stability. The ever-increasing rate of invasions has largely been attributed to the upward trend in human mobility and international trade (Liebhold et al. 1995, Vitousek et al. 1996, Mack et al. 2000). Information on the importance of various invasion pathways is essential for developing effective biosecurity strategies (Byers et al. 2002, National Research Council 2002). There has been substantial progress in characterizing invasion pathways of aquatic organisms (Carlton and Geller 1993, Gollasch 2002, Maki and Galatowitsch 2004) and of terrestrial invaders associated with commercial cargo operations (e.g., Bain 1977, Ridley et al. 2000, Haack 2001, Stanaway et al. 2001, Work et al. 2004, McCullough et al. 2005); however, efforts to study alien species associated with passenger travel are limited (Rainwater 1963).

Given the tremendous increases in global air passenger travel, there is a need to better characterize the extent to which air passenger baggage serves as an invasion pathway for alien species. Many countries expend large sums of money to screen baggage, but it is not clear whether these efforts are justified.

Our objective was to characterize the types of alien insect species that are transported in air passenger baggage. We analyzed pest interception records collected at airports in the United States from 1984 to 2000. In this article, we present broad statistical trends in the numbers and types of insect interceptions made at U.S. airports.

We also illustrate the use of these kinds of data by describing patterns of arrival in the United States of the exotic tephritid Mediterranean fruit fly, *Ceratitis capitata* (Wiedemann). This species has been detected in North America in numerous locations, and these finds have triggered several eradication campaigns. Some controversy has surrounded *C. capitata* eradication projects in southern California, and central to these controversies have been questions of whether sequentially detected populations represent the same colony or are the result of multiple introductions (Carey 1991).

Methods

Beginning with the Plant Quarantine Act of 1912 (7 U.S. Code, Sections 151–167) and most recently the Plant Protection Act of 2000 (7 U.S. Code, Title 4, Sections 410–442), Congress has entrusted the USDA with the task of securing the nation's borders from invasions by alien plant pests. Under that mandate, inspectors from the USDA APHIS Plant Protection and Quarantine searched for plant pests from a variety of incoming materials, including industrial and agricultural cargo. In March 2003, the responsibility for passenger and most cargo inspection was transferred to the Department of Homeland Security. Officers also are in charge of inspecting baggage of passengers arriving by all modes of transportation (air, sea, train, and auto).

Of all the modes of passenger transportation into the United States, almost all interceptions of insect pests in baggage come from passengers arriving by air (85% air, 14% border stations, <1% maritime [McCullough et al. 2005]). Most baggage inspections are done at the major international airports: Dallas, Chicago, Houston, New York, Los Angeles, Miami, and San Francisco. Airports in Hawaii and Puerto Rico conduct predeparture inspections to screen baggage of passengers embarking on flights to the continental United States (Fig. 1).

The selection of passengers whose baggage is subjected to inspections by quarantine officers in airports is not a random sample, but it is based on selection criteria that may be unique for each airport and may vary among different years. Inspections are designed to locate quarantine materials (e.g., live plants) that pose risks to U.S. agriculture. The nonrandomness of these searches must be considered when interpreting summaries of detections.

Whenever Department of Homeland Security or APHIS personnel encounter a pest of quarantine significance ("actionable") during baggage inspections, the interception is recorded on PPQ Form 309A. Pests of quarantine significance include live plant-feeding insects, mites, and mollusks, plant pathogens, weeds, and nematodes. Organisms that are dead upon arrival, groups that colonize only in dead plant material such as lumber, native species or nonindigenous species with cosmopolitan distributions, and non–plant-feeding organisms such as predators generally are not recorded. Up to 35 variables can be entered for each interception, including the taxonomic identity of the organism, the airport where it was intercepted, the type of plant that the insect was found on, and the country of embarkation listed on the passenger's ticket. Taxonomic resolution may vary depending on the life stage of the organism, its condition, and the expertise or workload of the APHIS identifiers. Specimens may at times be sent to specialists or reared for identification. Abundance or frequency of plant pests that are intercepted from an individual passenger's baggage usually are not recorded because of time constraints and because the discovery of a single actionable pest typically results in confiscation and destruction of the infested material.

Data on each Form 309a are entered into the Port Information Network (PIN) database, which is implemented as a Sequential Query Language (SQL) database. We analyzed the portion of this database spanning the period 1 January 1984 through 31 December 2000. We excluded pest interception records that contained incomplete or invalid taxonomic identifications or ambiguous points of entry or origin.

Frequencies of interceptions were tabulated by country of origin, and we compared these frequencies with statistical data on air travel. Air travel data consisted of the "Historical Air Traffic Statistics, Annual 1954–1980" collected by the U.S. Department of Transportation Bureau of Transportation Statistics (http://www.bts.gov/oai/indicators/airtraffic/annual/1954-1980.html) and the "International Arrivals to the U.S.—Historical Visitation 1994–2000" recorded by the Office of Travel & Tourism Industries. (http://tinet.ita.doc.gov/view/f-2000-04-001/index.html?ti_cart_cookie=20010627.193317.20080)

Results and Discussion

Between 1984 and 2000, 290,101 alien insect interceptions from air baggage were recorded at all international airports in the United

Fig. 1. Department. of Homeland Security or USDA APHIS PPQ personnel perform inspections of international air passenger baggage arriving at airports across the US every day. Some airports use beagles, scanning devices, or other equipment to aid in screening baggage for quarantine material.

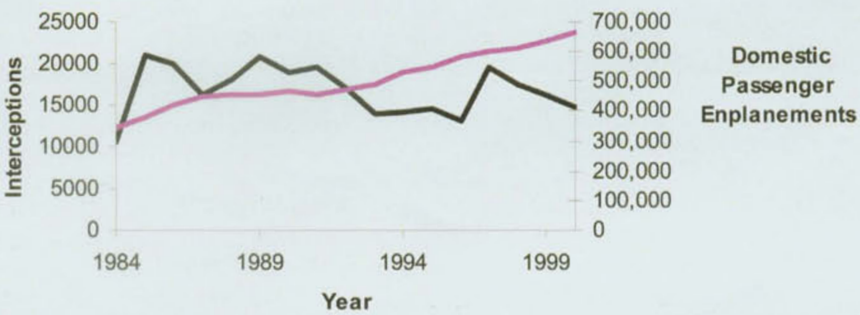

Fig. 2. Historical records of insect interceptions (black) and domestic passenger emplanements (thousands) (purple)

States. Although there was a steady increase in numbers of international air passengers, that trend was not reflected in the numbers of alien insect interceptions, which fluctuated around 15,000 per year (Fig. 2). The most likely explanation for the lack of a parallel trend between these two time series is that interceptions were made by a generally constant work force despite the increasing numbers of passengers.

All the major insect orders were represented in air baggage (Fig. 3). Homoptera accounted for 45% of all reported interceptions but only 34% of intercepted species and 22% of intercepted genera. Similarly, 23% of all interceptions were Diptera, but only 3% of genera and 3% of species were Diptera. This indicates that even though the Homoptera and the Diptera were the most frequently intercepted, these interceptions were largely repetitions of the same species. In contrast, the Coleoptera and Heteroptera made up a relatively small fraction of total interceptions but represented a much larger fraction of genera (32 and 15%) and species. This indicates that Coleopteran and Heteropteran interceptions, while not extremely common, were a diverse group. These proportions contrast with estimates of known number of species by major insect order: 44% Coleoptera, 15% Diptera, 15% Lepidoptera (Strong et al. 1984). The differences in these frequencies may result, in part, from most inspections targeting (and reporting) herbivorous insects, whereas saprophytic, parasitic, and predatory species are generally not targeted for interception. For example, although Coleoptera make up 44% of all insect species worldwide, they represent only 33% of the world's herbivorous insects. Only 8% of the world's insect species are Homoptera, but they make up 15% of all herbivore species (Strong et al. 1984).

Another likely reason why the distribution of intercepted taxa differs from the distribution of species in the world's insect fauna is that baggage interceptions are disproportionately represented by insects infesting fruits (Fig.4a). Edible fruits and nuts are presumably transported by air passengers to eat during their journeys and perhaps because they are convenient and appreciated gifts compared with other plant parts. The most commonly intercepted fruit genus containing insects was *Mangifera* (mangos) (Fig. 3b). Of insects intercepted on mangos, most were members of the Diaspididae (49%), Tephritidae (33%), or Curculionidae (10%).

Interceptions were recorded from 316 countries of origin, although the 10 most common countries accounted for >50% of the interceptions (Fig. 4c). Much of the variability in numbers of interceptions among countries could be simply be accounted for by air traffic because the most frequent interceptions were from countries with the greatest number of passengers (Fig. 5). However, after accounting for air traffic, we also found that there were generally more interceptions in baggage originating from countries with developing economies. We fit the multiple regression model

$$y = a + b_1x_1 + b_2x_2$$

where y was the total number of interceptions, x_1 was the mean number of passengers arriving per year from the country of origin, and x_2 was the gross national product of the country of origin. Both coefficients, $b_1 = 0.107$ and $b_2 = -0.971$, were highly significant, indicating that air traffic was positively associated with the number of interceptions, and gross national product was negatively associated with interception rate. It is possible that the higher interception rates in baggage originating from developing economies are indicative of increased scrutiny of passengers from these countries; but we suspect that this relationship reflects a greater tendency of visitors from developing economies to transport unprocessed fruit, herbs, and other organic material that could host alien insect species. Variation in frequencies of interceptions among U.S. cities (Fig. 5d) largely reflected the variation in the volume of arriving international flights.

Case History: Mediterranean Fruit Fly

The Mediterranean fruit fly is one of the world's most destructive fruit pests. Host plants include avocado, banana, bittermelon, carambola (star fruit), coffee, guava, mango, papaya, peppers, and persimmon (Weems 1981, Liquido et al. 1991). The species apparently originated in sub-Saharan Africa and subsequently invaded parts of southern Europe, Central and South America,

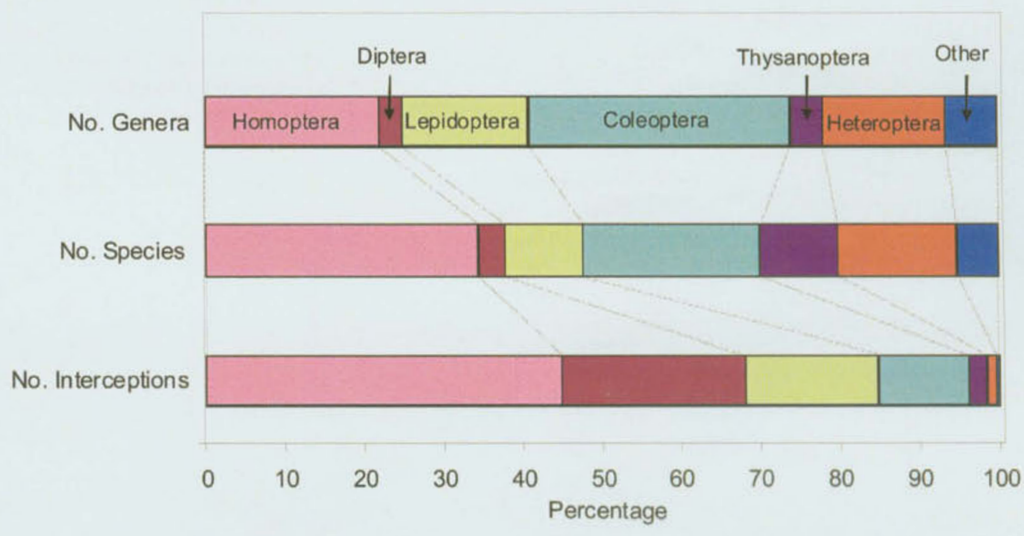

Fig. 3. Frequencies of different insect orders intercepted in baggage interceptions expressed as numbers of genera, numbers of species, and total numbers of interceptions. The "other" category includes Hymenoptera, Orthoptera, Isoptera, and Collembola.

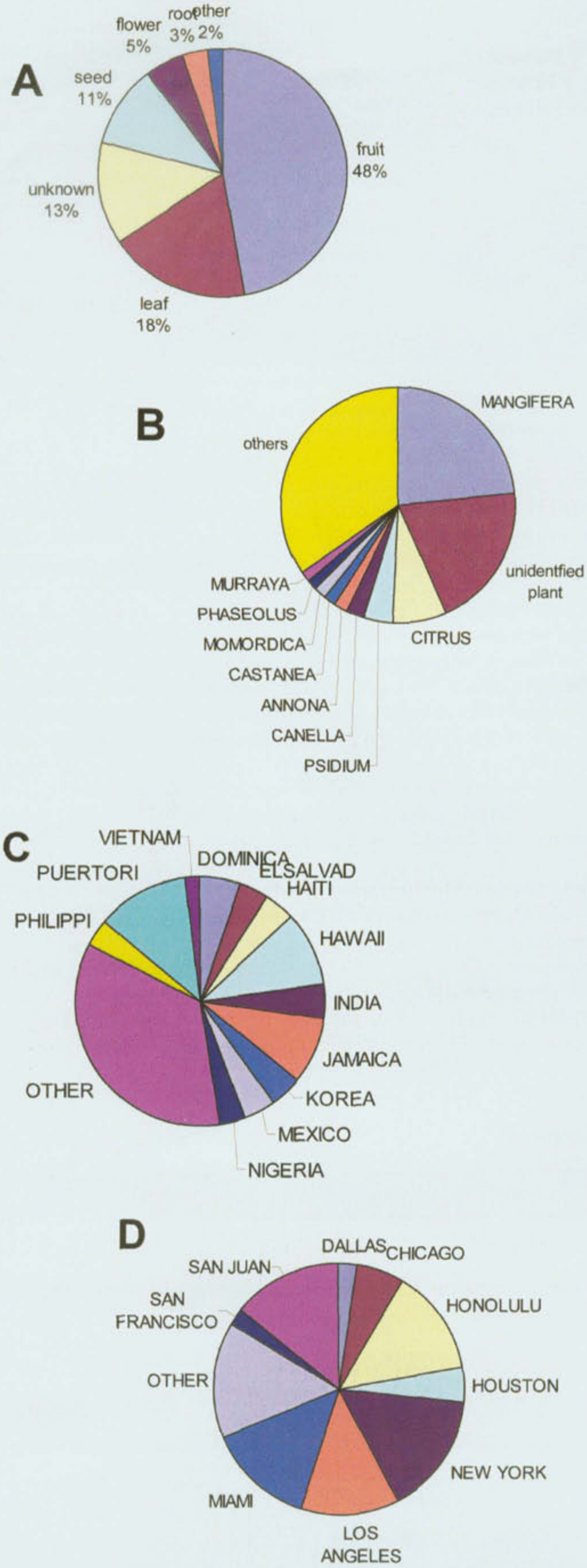

Fig. 4. Frequency of insect interceptions (a) by plant part; (b) by plant genus; (c) by country of origin; (d) by airport.

the Caribbean, the South Pacific Islands and Australia. *C. capitata* has been established in Hawaii for nearly 100 years; however, it is not known to be established in the continental United States. It has been detected repeatedly in Florida and California, and these detections have triggered extensive eradication programs (Ayers 1957, Carey 1991).

Seasonal patterns of interceptions of specimens identified as *C. capitata* are shown in Figure 6a. The vast majority of the intercepted specimens originated from either Europe or the Middle East, and there was a distinct seasonality because almost all material was intercepted in late summer or early fall. This distribution coincides with the seasonal distribution of generations 3–5 in the Mediterranean region, and this is when *C. capitata* populations reach their highest levels in fruit (Papadopoulos et al. 2001).

Most of the intercepted Mediterranean fruit flies are collected as larvae because adults are unlikely to be present on fruit in baggage. Because of the lack of distinctive larval characteristics, positive identification of larval *C. capitata* was based not only upon morphology, but also host and origin. However, because of the difficulty in identifying larvae, it is likely that many, or most, intercepted Mediterranean fruit flies could only be reliably identified to the family, Tephritidae, or tribe, Ceratitini. Indeed, large numbers of unidentified Ceratitini originated in Africa (Fig. 6b), and it is likely that at least some of these may have been *C. capitata*. The less distinct seasonal distribution of interceptions of these unidentified taxa may be expected, based upon the more equatorial climate of Africa. Large numbers of specimens were identified simply as Tephritidae (Fig. 6c) from the Pacific Islands (e.g., Hawaii) and Africa; many of these specimens also may have been *C. capitata*.

The interception history of specimens identified as *C. capitata*, "unidentified Ceratitini" or "unidentified Tephritidae" indicates that *C. capitata* arrivals have occurred at sustained high levels at U.S. airports for many years (Fig. 7). Climates in Los Angeles and Miami are probably the most suitable for establishing Mediterranean fruit flies. Even though interceptions of *C. capitata*, "unidentified Ceratitini," and "unidentified Tephritidae" were comparatively low, interception rates were sustained at high enough levels to be of concern relative to establishment of populations in these cities. From 1984 to 2000, there were 116 interceptions of *C. capitata* in Miami and 56 in Los Angeles; many more interceptions of unidentified Ceratitini and unidentified Tephritidae were made in both cities, and many of these were likely to have been *C. capitata*.

Carey (1991) presented a hypothesis that recurrent trap recaptures of *C. capitata* in California from 1970 to 1990 were due to the existence of established populations. This hypothesis was in stark contrast to that held by state and federal regulatory agencies that *C. capitata* had been repeatedly eradicated from California

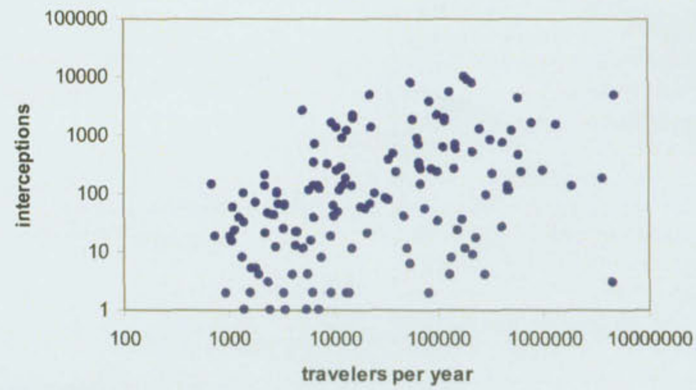

Fig. 5. Relationship between number of insect interceptions and travelers per year.

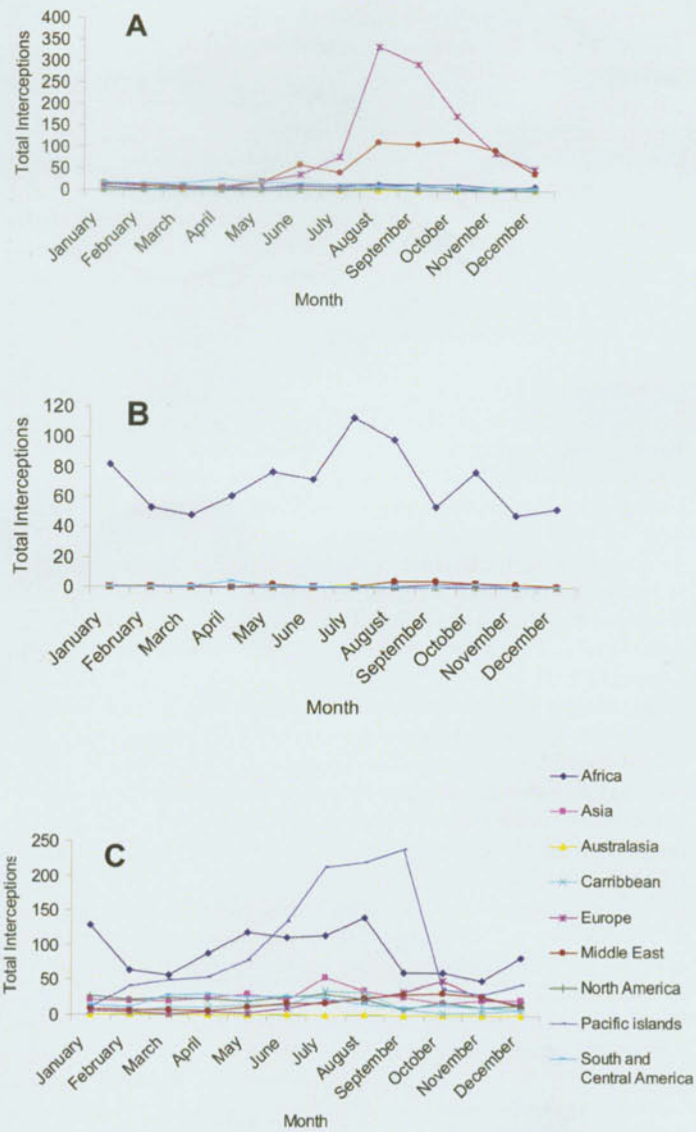

Fig. 6. Seasonal distribution of interceptions of insects identified as (a) *Ceratitis capitata* (Mediterranean fruit fly); (b) Unidentified Ceratitini; (c) Unidentified

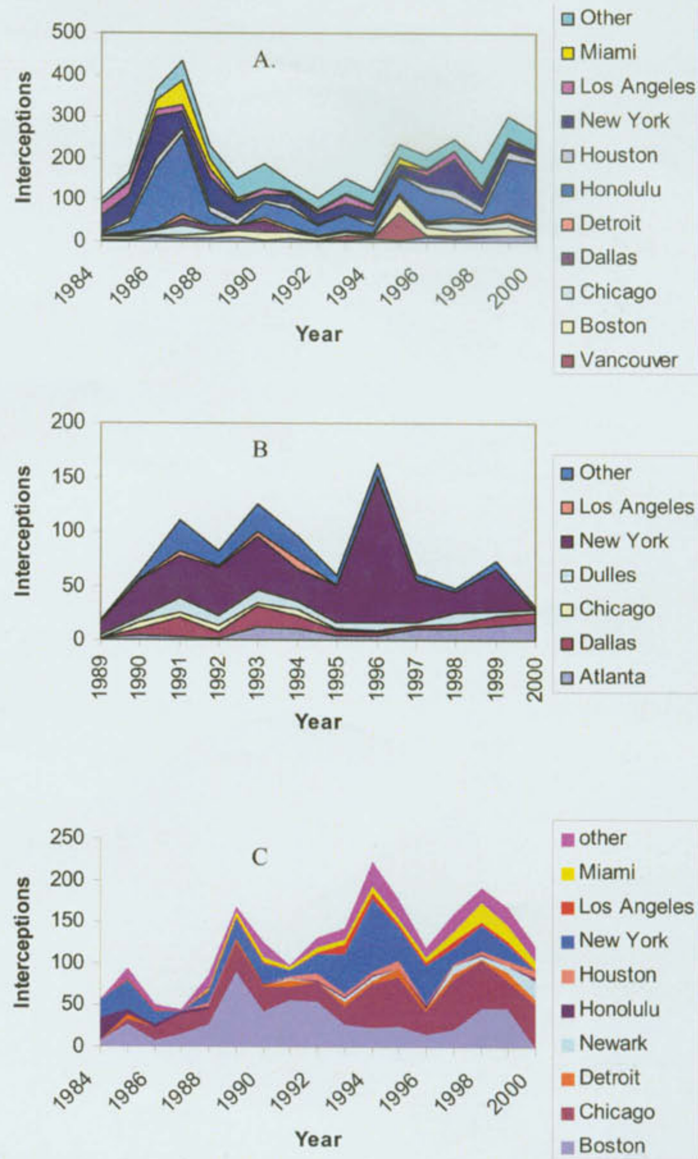

Fig. 7. Interceptions of fruit flies. (a) Unidentified tephritids by airport; (b) Unidentified Ceratitini by airport. (c) *Ceratitis capitata* by airport.

and that recurrent trap captures were due to reintroduction of new populations. A crucial part of the theory advanced by Carey was that historical data indicated very low arrival rates of *C. capitata* in the Los Angeles area. Indeed, he analyzed PIN data from 1985 through part of 1990 and reported that only five interceptions of *C. capitata* occurred at any of the three international airports in California (Los Angeles, San Diego, and San Francisco).

In our analysis, we looked at a longer time series of interception records and found a much higher rate of *C. capitata* interception in Los Angeles (3.7 interceptions per year of specimens identified as *C. capitata* at LAX and an additional 16.3 interceptions per year of unidentified Ceratitini/Tephritidae, many of which were likely *C. capitata*). Because only a tiny fraction of incoming passengers are subjected to inspections, it is likely that undetected transport of Mediterranean fruit fly in air baggage entering Los Angeles has been a common phenomenon. Thus, our analysis indicates a recurrent flow of *C. capitata* into southern California and, contrary to Carey's conclusion (1991), indicates that arrival rates can explain the repeated detection of this species in California.

We found that 83% of insects identified as *C. capitata* that were intercepted in Los Angeles originated in either Europe or the Middle East, similar to the pattern for all airports (Fig. 6a). But these results do not necessarily indicate that isolated *C. capitata* populations detected over the past 20 years in California are of European or Middle Eastern origin because interceptions of *C. capitata* also have been made from other parts of the world, albeit at lower rates (Fig. 6a). Many interceptions of unidentified Ceratitini and Tephritidae originated from throughout the world (especially Africa and Pacific Islands) (Fig. 6b,c), and many of these may have been the Mediterranean fruit fly. In fact, genetic analyses by Davies and Roderick (1999) and Bohonak et al. (2001) indicated that *C. capitata* populations detected in southern California most likely originated from Latin America.

Frequencies of hosts associated with intercepted tephritids and *C. capitata* are shown in Fig. 8. Most of the hosts of insects that were positively identified as Mediterranean fruit fly were *Ficus*, followed by *Psidium* and *Prunus*. This differed substantially from the

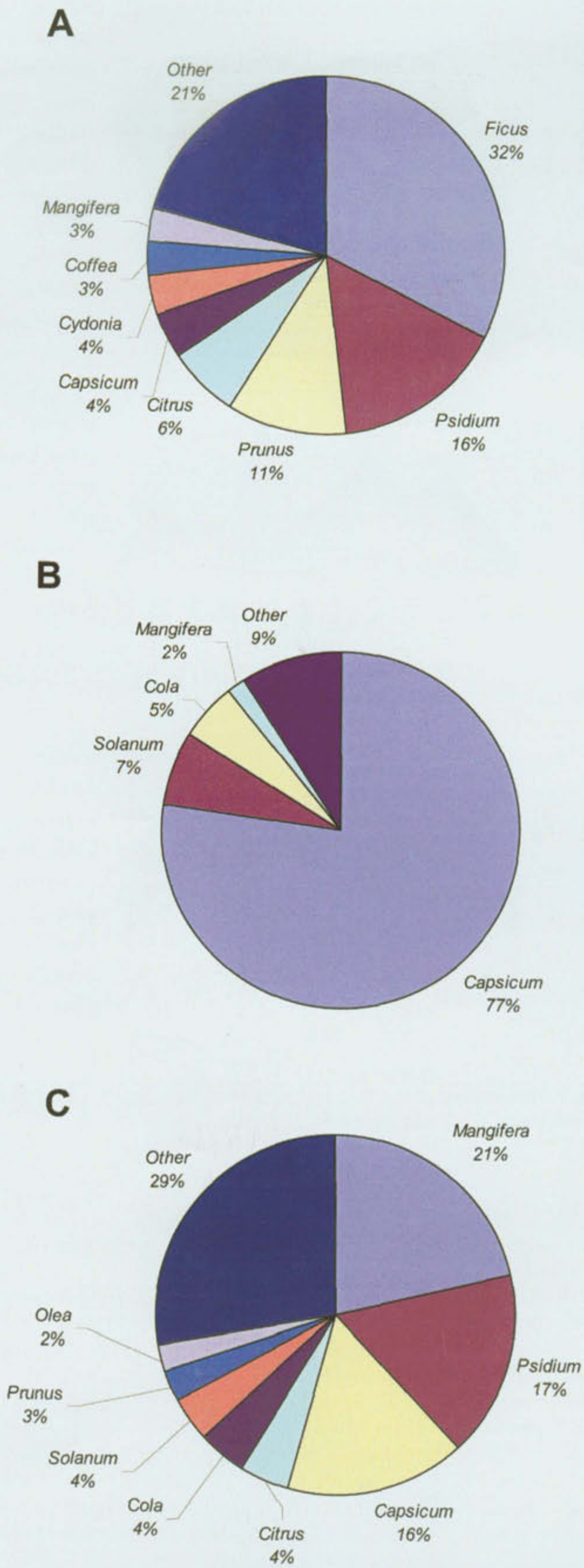

Fig. 8. Host genera. (a) for *Ceratitis capitata* intercepted; (b) for unidentified Ceratitini intercepted; (c) for unidentified Tephritidae intercepted.

hosts of unidentified Ceratitini, which were predominately associated with *Capsicum* (peppers), and unidentified Tephritidae, which were primarily associated with *Mangifera*, *Psidium* (guavas), and *Capsicum*. Because all of these are suitable hosts, some proportion of these intercepted insects may have been *C. capitata*. It is likely that the host associations recorded here for Mediterranean fruit fly do not reflect the true associations for this insect. As we stated earlier, positive identification of intercepted larvae as *C. capitata* is typically based in part on the country of origin and the taxa of the host. Although many different Tephritids are associated with mango, fewer are associated with *Ficus*, and thus there is a greater likelihood of identification to the species level.

Conclusions

Because inspectors only check a small fraction of passenger baggage entering the United States by air, these inspections may not be preventing most incidents involving the entry of alien insects via baggage. For example, rates of interceptions have not kept up with the steady increase in international air travel (Fig. 1). Considering the destructive nature of alien species invasions, it is likely that increased scrutiny of passenger baggage would be a cost-effective strategy to reduce future invasions and minimize the costs involved with impacts and eradication (National Research Council 2002).

In contrast to the United States, New Zealand and Australia have much more aggressive baggage inspection programs. All baggage of air passengers entering these two countries is subjected to an X-ray scan for contraband quarantined goods, and this effort yields a much higher rate of interception of plant pests than the current inspection program in the United States (New Zealand Ministry of Agriculture and Forestry 2002).

Although current U.S. baggage inspection procedures are not 100% effective in locating quarantine items, they do have a major benefit—the collection of data about which taxa are entering via specific baggage pathways. Our analyses illustrate the value of this information. For example, these data indicate that fruit in baggage is as an important pathway for the arrival of alien insects, especially for exotic Homoptera and Diptera. These infested fruits appear to be most commonly found in the baggage of passengers arriving from developing countries. The more detailed analysis of Mediterranean fruit fly entry indicates that this species is entering the country primarily by way of infested fruit and reaches its maximum during the late summer and fall months. Contrary to a previously published analysis of the PIN data, our analysis suggests that there has been a continual flow of Mediterranean fruit fly life stages arriving in southern California. This sustained level of arrival can explain the repeated detection of this insect in southern California, even after its repeated eradication. Although interception records, such as those analyzed here, give critical information for characterizing invasion pathways, they would be more useful if inspection activities were entirely part of a statistically designed sampling program that would make it possible to estimate actual arrival rates (Work et al. 2004). The fact that baggage inspections are not random limits their use in estimating approach rates for various species associated with specific pathways. Of course, to optimize inspection programs as a tool for preventing arrival of alien species, scrutiny of baggage according to its origin and destination must be increased. Thus it would appear that although it would be advisable to increase resources devoted to baggage inspection as a way of minimizing future invasions, it would also be advisable to develop a statistically based sampling program that would allow more precise estimation of approach rates. Although such a program currently exists for sampling cargo arriving in the United States (Work et al. 2004), it does not exist for baggage.

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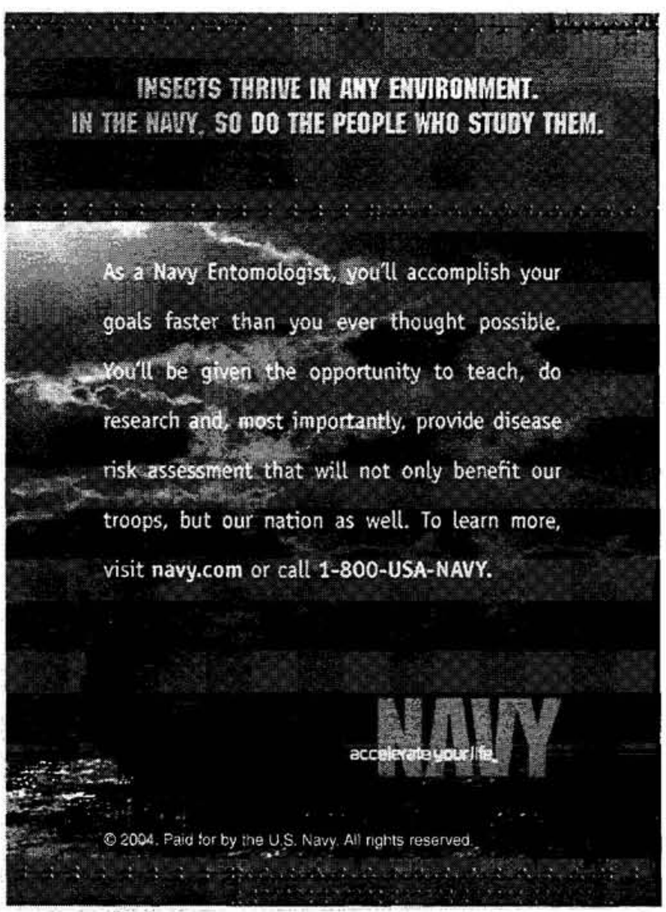

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