Biological Invasions (2006) 8: 611–630
DOI 10.1007/s10530-005-1798-4

Interceptions of nonindigenous plant pests at US ports of entry and border crossings over a 17-year period

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Received 2 December 2004; accepted in revised form 4 February 2005

Key words: exotic insects, exotic species, exotic weeds, invasion pathways, nonindigenous pest arrival, Port Information Network database

Abstract

Despite the substantial impacts of nonindigenous plant pests and weeds, relatively little is known about the pathways by which these organisms arrive in the U.S. One source of such information is the Port Information Network (PIN) database, maintained by the U.S. Department of Agriculture, Animal and Plant Health Inspection Service (APHIS) since 1984. The PIN database is comprised of records of pests intercepted by APHIS personnel during inspections of travelers' baggage, cargo, conveyances and related items arriving at U.S. ports of entry and border crossings. Each record typically includes the taxonomic identify of the pest, its country of origin, and information related to the commodity and interception site. We summarized more than 725,000 pest interceptions recorded in PIN from 1984 to 2000 to examine origins, interception sites and modes of transport for nonindigenous insects, mites, mollusks, nematodes, plant pathogens and weeds. Roughly 62% of intercepted pests were associated with baggage, 30% were associated with cargo and 7% were associated with plant propagative material. Pest interceptions occurred most commonly at airports (73%), U.S.-Mexico land border crossings (13%) and marine ports (9%). Insects dominated the database, comprising 73 to 84% of the records annually, with the orders Homoptera, Lepidoptera and Diptera collectively accounting for over 75% of the insect records. Plant pathogens, weeds and mollusks accounted for 13, 7 and 1.5% of all pest records, respectively, while mites and nematodes comprised less than 1% of the records. Pests were intercepted from at least 259 different locations. Common origins included Mexico, Central and South American countries, the Caribbean and Asia. Within specific commodity pathways, richness of the pest taxa generally increased linearly with the number of interceptions. Application of PIN data for statistically robust predictions is limited by nonrandom sampling protocols, but the data provide a valuable historical record of the array of nonindigenous organisms transported to the U.S. through international trade and travel.

Introduction

Nonindigenous, invasive plant pests and weeds have dramatically affected the diversity, productivity and function of natural and agricultural ecosystems throughout North America (U.S. O.T.A. 1993; Liebhold et al. 1995; Vitousek et al. 1996; Wilcove et al. 1998; Mack et al. 2000;

Pimental et al. 2000). Successful invasion involves a three-step process: the nonindigenous species must arrive in its new habitat, become established, then increase in density and expand its range (NRC 2002). Only a fraction of the nonindigenous organisms that arrive become established and invasive (Williamson and Fitter 1996). Once a nonindigenous species becomes established, however, management options are typically limited to eradication or regulatory programs to contain or slow the spread of the pest. These efforts are usually costly, may require intensive pesticide applications and are not always successful (Dahlsten et al. 1989; Myers et al. 2000; Simberloff 2001; Liebhold and Bascompte 2003).

International trade has long been recognized as a major conduit by which nonindigenous plant pests arrive in the United States (Rainwater 1963; Kahn 1991; U.S. O.T.A. 1993; National Plant Board 1999). Insects, plant pathogens and other organisms may colonize or hitchhike on agricultural commodities imported as food or for processing, on nonagricultural cargo, and on produce or plants carried into the U.S. in baggage accompanying travelers. Nursery stock and other plant material intended for propagation may be a particularly dangerous pathway if the pest accompanies its host plant into the new habitat (Sailer 1978; Niemela and Mattson 1996; NRC 2002). Solid wood packing material, including crating, pallets and dunnage, has been identified as a high-risk source of introductions of organisms such as bark beetles, woodborers and wilt or stain fungi (Ridley et al. 2000; USDA-APHIS-FS 2000; Stanaway et al. 2001).

Recent reviews have noted the importance of intercepting nonindigenous pests at the border, before they have the opportunity to become established (Mack et al. 2000, NRC 2002). The magnitude of this task is considerable, however, given increasing trends in globalization and the volume of trade and travel among countries (Doggett 1997; National Plant Board 1999; USDA ERS/FATUS 2001; NRC 2002). Information about the abundance, origin and commodities associated with the arrival of nonindigenous organisms would be useful for refining inspection and detection programs, identifying relative risks posed by imported commodities and developing international trade policies. Increased knowledge about the pathways by which nonindigenous plant pests arrive at U.S. borders, could, moreover, provide a framework for developing testable hypotheses about economic or ecological factors related to invasion success.

The U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Plant Protection and Quarantine division (USDA APHIS PPQ) is responsible for excluding nonindigenous pests of plants, including phytophagous insects and mites, mollusks, nematodes, plant pathogens and noxious weeds from the United States. Inspections of baggage carried by international travelers and international cargo that arrives at U.S. ports and border crossings focus primarily on agricultural and plant-related commodities that are likely to harbor live plant pests. These inspections have been conducted for decades and in past years, APHIS published lists or summaries of intercepted pests.

Since 1984, APHIS personnel have maintained an electronic database of the nonindigenous organisms intercepted on materials arriving from foreign countries. This database, known as the Port Information Network or "PIN" data, exists on a mainframe computer in Maryland. Each record in the PIN database represents an interception event and new records are added daily. Variables associated with each record can include the taxonomic identity of the organism, its country of origin, the location and date of interception, and the commodity bearing the invader. Personnel at APHIS use the PIN database internally to develop inspection protocols, train and assign personnel, monitor pest risk of selected import pathways and identify patterns in interception rates. These data have rarely been made available to scientists outside the APHIS organization, however, because of the complexity of the database and the potential for misinterpretation or even international trade disputes. Subsets of the PIN data were recently applied to characterize historical introductions of Karnal bunt, a disease of wheat caused by the fungus *Tilletia indica* (Marshall et al. 2003) and to summarize the origin and diversity of phloem and wood-boring beetles (Haack and Cavey 1997; Haack 2001).

There are recognized limitations with the PIN data. The types of baggage, shipments or commodities that are inspected and therefore represented in the PIN data are not randomly selected. Targeted commodities and inspection procedures evolve over time, depending on the pests or commodities of concern to APHIS at a given time or locality. Records in the PIN database generally include only pests of quarantine significance, which means that, in effect, PIN data represent a subsample of all intercepted organisms. Nevertheless, these data provide a unique historical record of the array of plant pests that enter the country and the pathways by which they arrive.

The goal of this paper is to present an overview and general description of the relative rates and circumstances associated with interceptions of plant-feeding insects, mites, mollusks, nematodes, plant pathogens and weeds at U.S. borders and ports of entry. We summarized PIN data from 1984 to 2000 to examine the origins, interception sites and mode of transport associated with the pest taxa.

Methods

Records of nonindigenous organisms that are intercepted by APHIS personnel during inspections of baggage, cargo and mail associated with transport vessels originating outside the U.S. are captured in the PIN database if the organism is considered an actionable pest of quarantine significance. An actionable pest refers to an organism that typically elicits some type of mediation by APHIS such as treatment, rejection or destruction of the infested material. Pests of quarantine significance include live plant-feeding insects, mites and mollusks, plant pathogens, and nematodes. Plants or plant seeds that are intercepted are recorded in PIN only if they are listed on the U.S. Federal Noxious Weeds list (USDA Federal Register 2004, USDA APHIS PPQ 2004). Insects or other organisms that are dead upon arrival, organisms that colonize only dead plant material such as lumber, native species, nonindigenous species with cosmopolitan distribution and organisms such as predators that are not phytophagous are generally excluded from the PIN database. Up to 35 variables can be entered for each interception, including the taxonomic identity of the organism, the port or border crossing where the interception occurred, the country of origin, commodity and method of conveyance associated with the pest, along with information used internally by APHIS personnel. Taxonomic resolution may vary depending on the life stage of the organism, its condition and the expertise or workload of APHIS identifiers. Specimens may at times be sent to specialists or in rare cases, may be cultured or reared for identification. Abundance or frequency of pests that are intercepted in a single shipment are generally not recorded due to time constraints or inaccessibility of portions of the shipment. Discovery of a single actionable pest typically results in regulatory action, negating the need for further inspection.

The PIN data we analyzed were collected by APHIS PPQ personnel during inspections of cargo, baggage and related items arriving at 42 airports, 25 maritime ports and 33 land border sites where travelers or cargo cross into the U.S. from Mexico or Canada. An additional 24 locations receive air and maritime cargo and passengers, three sites were classed as air/maritime/land border (e.g. San Diego, CA), one site was an air/land border and one site was classed as maritime/land. Seventeen ports of entry were designated as plant inspection stations where most plant material imported for propagation must pass through rigorous screening by specially trained personnel. Nine of these plant inspection stations are located in airports on the east or west coasts of the U.S., four are along the U.S.-Mexican border and single stations are located in Hawaii and Puerto Rico. In addition, predeparture inspections are conducted in Hawaii and Puerto Rico to screen baggage of passengers embarking on flights to the continental U.S. and cargo destined for U.S. mainland ports.

We downloaded the PIN database in July 2001 for the period encompassing January 1, 1984 through June 2001. Entry of records into PIN can be delayed, however, because of heavy workloads or pending taxonomic resolution of intercepted organisms. Therefore, we restricted our analysis to interceptions that occurred from 1 January 1984 through 31 December 2000, to ensure that nearly all interceptions from this period would be included in the database. We converted the PIN data from an ASCII format into a relational database using MSAccess to query and cross-index the data. The PIN dataset from 1984 through 2000 consisted of 775,651 records, each representing a pest intercepted in baggage or cargo at a point of entry into the U.S. or U.S. territories. We grouped the records into six major taxa; insects, mites, mollusks, nematodes, plant pathogens and weeds. Records were intensively examined to correct entry or typographical errors. Pest interception records that contained incomplete or invalid taxonomic identifications (21,949 records) or ambiguous point of entry or origin identifications (18,384 records) were excluded from our analysis. Interceptions recorded at inspection stations in foreign countries (6328 records) were also excluded. Inspection protocols at these stations are often designed to detect a specific target pest associated with commercial shipments of produce destined for the U.S. and the records are unlikely to reflect the potential pest distribution at these sites in the same manner as other records.

Trends in pest interceptions and potential invasion pathways were assessed by evaluating the number and location of points of origin and points of entry, and the type of infested commodities for all interceptions and for the six taxa. Baggage and cargo records were analyzed separately in some cases because of differences in inspection protocols, pest composition and port–origin relationships. Baggage refers to materials carried on board or in the luggage of passengers who arrive in the U.S. on ships or airplanes, or cross into the U.S. from Mexico or Canada by foot or on personal vehicles. Cargo refers to commercial shipments of materials arriving at U.S. airports, marine ports or transported in trucks crossing U.S. borders. General trends in the origins of the plant pest taxa were determined for major world regions, as well as by country. Pests intercepted at preclearance stations in Puerto Rico and Hawaii were included in the Caribbean and Pacific regions, respectively.

Results

A total of 728,990 pest interceptions, representing at least 2,340 species, were used in our analysis. Pests were intercepted at 160 points of entry into the U.S. and seven points of entry into U.S. territories. On average, there were 42,882 (SE ± 1,986) pest interceptions recorded annually from 1984 to 2000, ranging from a low of 19,697 in 1984 to a high of 55,522 in 1997 (Figure 1).

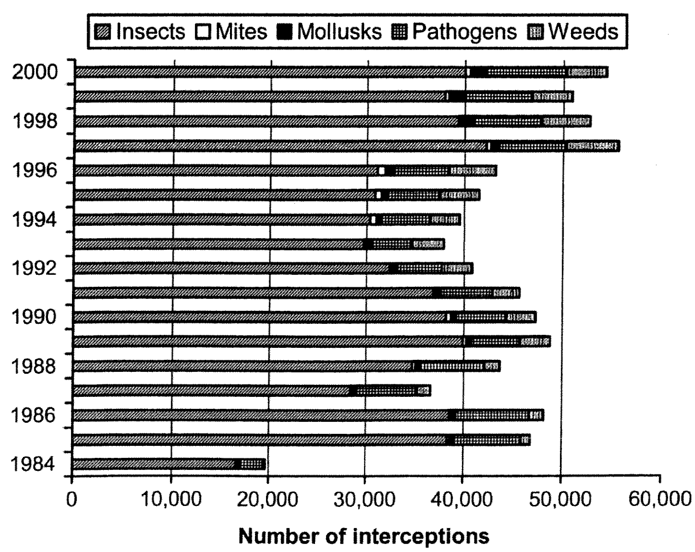

Figure 1. Number of interceptions of nonindigenous plants and plant pests by taxa and year from 1984 to 2000.

Number of interceptions by month ranged from a total of 54,515 interceptions (7.07% of all records) in December to 73,542 records (9.54% of records) in May. There were 259 different origins recorded for intercepted pests. While 260 countries can be identified in the world today (CountryWorld.org 2005), there are currently 192 countries recognized by the U.S. State Department (WorldAtlas.com 2005). In some PIN records, an individual island was listed as the origin of the pest instead of the name of a collective group of islands (e.g. St. Thomas instead of the Virgin Islands). Other records listed a territory or colony as the pest origin, and in some cases, names or political designations of countries changed over the 17-year period. Pre-departure stations in Hawaii and Puerto Rico that clear agricultural products shipped as cargo and produce carried by travelers prior to their arrival in the continental U.S. accounted for 8.5 and 7.7% of all interceptions, respectively. Insects dominated the PIN database, comprising 77.5% of all records (Table 1). Plant pathogens, weeds and mollusks made up 13.1, 6.9 and 1.6% of the interceptions, respectively. Interceptions of mites (0.8%) and nematodes (0.1%) accounted for the remainder of the records.

Overall, 87% of pests in the PIN database were intercepted on imported commodities intended for consumption including 89% of insects, 80% of pathogens, 82% of weeds and 78% of mollusks. This category includes items such as fruit, vegetables and cut flowers, along with machinery and building materials. An additional 7% of the records were associated with plant materials intended for propagation such as live plants, cuttings, bulbs, seeds and roots. Propagative material, which is examined intensively at plant inspection stations upon entry, was associated with 48% of mite interceptions and 43% of nematode interceptions. Roughly 6% of the pests were intercepted on materials classified as "non-entry," which indicates that the material associated with the pest is not allowed entry into the United States. A pest found on vegetables in the storeroom of a cargo ship, for example, is so designated because APHIS policy requires that those items remain on the ship. Non-entry items included dunnage (wood or other material used to support cargo on ships), ship's stores, holds of cargo ships or crew's quarters. Overall, 6% of insects, 12% of mites, 14% of pathogens, 14% of weeds, 4% of mollusks and 16% of nematodes were associated with non-entry items. The remaining pests (roughly 1.5% of the records) were collected from mail containers or miscellaneous locations such as the outside of conveyance vehicles.

More than half of all pest interceptions (62.0%) were associated with baggage carried by travelers entering the United States (Table 2). Baggage was the most common item of conveyance for four of the six taxa, accounting for 60.5% of insect records, 49.1% of nematodes, 68.3% of pathogens and 83.8% of weeds, but only 25.5% of mites and 14.2% of mollusk records. Not surprisingly, fruit was the most common commodity associated with insect and mite interceptions on baggage and nearly half of all pests intercepted in baggage came from

Table 1. Number of nonindigenous plants and plant pests intercepted from 1984 to 2000 from major world regions or continents.

World region	Insects	Mites	Mollusks	Nematodes	Pathogens	Weeds	Total
Central & South America	137,335	3199	1540	74	17,318	2206	161,672
Caribbean	106,474	254	327	8	16,167	11,153	134,383
North America[a]	96,209	1060	146	32	18,184	5158	120,789
Asia	76,918	340	980	139	20,373	20,493	119,243
Europe	57,408	964	6529	137	2522	674	68,234
Pacific Region	48,286	30	199	9	17,010	724	66,258
Africa	25,202	79	644	24	2278	1424	29,651
Middle East	13,058	95	1046	17	811	8052	23,079
Australasia	4156	50	115	4	1182	174	5681
Total	565,046	6071	11,526	444	95,845	50,058	728,990

[a]Mexico was the origin of 99.5% of North American interceptions.

Table 2. Number of nonindigenous plants and plant pests intercepted from baggage or cargo for nine categories of commodities.

Commodity	Insects	Mites	Mollusks	Nematodes	Pathogens	Weeds	Total	Percent of total records[a]
Cargo								
Bulb	591	3	8	2	6	27	637	0.28
Cut flowers	79,934	424	1716	6	1719	95	83,894	37.3
Cutting	4860	1090	800		843	31	7624	3.39
Fruit	37,680	485	130	3	723	176	39,197	17.45
Not applicable	9069	10	4661	6	121	215	14,082	6.27
Plant part	50,154	2043	1670	52	10,124	389	64,432	28.68
Seed	1526		9	12	533	5325	7405	3.30
Soil	39		10	25	1	4	79	0.04
Wood products	6960	1	295		6	20	7282	3.24
Total	190,813	4056	9299	106	14,076	6282	224,632	
Baggage								
Bulb	371	3	10		7	2	393	0.28
Cut flowers	21,900	187	61	1	3878	14	26,041	37.3
Cutting	4905	50	48	1	1534	71	6609	3.39
Fruit	195,707	963	65	7	19,844	7730	224,316	17.45
Not applicable	3469	41	1048	11	217	12,638	17,424	6.27
Plant part	88,395	300	374	153	39,319	311	128,852	28.68
Seed	26,509	5	17	1	675	20,939	48,146	3.30
Soil	156		13	44	7	7	227	0.04
Wood products	196		1		1		198	3.24
Total	341,608	1549	1637	218	65,482	41,712	452,206	

[a]Percentage of the total 728,990 records represented by pest interceptions associated with these commodity pathways.

confiscated fruit (Table 2). Plant parts, a category that includes ornamental plants and some propagative material, was the most common commodity associated with pathogen and nematode interceptions in baggage and was also frequently associated with insect interceptions. Mollusk interceptions were much lower in baggage than in cargo and almost 65% of the interceptions were not associated with any specific commodity. Weeds intercepted in baggage were most often associated with material categorized as seeds, which could include spices such as cumin carried by travelers.

Most of the remaining interceptions (30.8%) were associated with cargo, which is classified by APHIS as either permit cargo or general cargo. Permit cargo typically refers to agricultural products that require an APHIS permit for entry into the United States or cargo that is regulated for specific pests. Examples include shipments of fruit or other produce and nursery stock or other plant material destined for propagation. General cargo primarily refers to non-agricultural commodities, (i.e. tools, machinery, shoes, clothing and toys). Some items classified as general cargo such as cut flowers and tiles, however, were associated with high numbers of plant pest interceptions and may represent important pathways for nonindigenous species arrival (Table 2). Permit cargo accounted for almost 24% of all interceptions and general cargo comprised an additional 8% of interceptions. Cargo accounted for 33.8% of all insect interceptions, 67.0% of the mites, 80.7% of the mollusks, 23.9% of the nematodes, 14.7% of the pathogens and 12.5% of the weeds. Insect interceptions in cargo were most frequently associated with cut flowers, plant parts and fruit, while mites were most frequently associated with plant parts and plant cuttings (Table 2). Plant pathogens arriving with cargo were most commonly detected when plant parts were inspected. Relatively high numbers of mollusks were intercepted on plant parts and cut flowers shipped as cargo. Roughly 50% of mollusks were not associated with specific commodities, a situation that can occur when snails or slugs hitchhike on or within shipping containers. Most of the weeds intercepted with cargo were again associated with seeds.

Overall, more pest interceptions were made at airports receiving international flights (73%) than at any other type of station. Interceptions at airports included many pests recovered from travelers' baggage as well as pests associated with air cargo. Land border inspection stations, primarily on the U.S.-Mexico border, and marine ports where cargo ships are unloaded, recorded 13 and 9% of pest interceptions, respectively. When interceptions were grouped by taxa, interceptions at airports accounted for 80% of all weeds, 75% of insects, 67% of pathogens and 57% of nematodes. Land border inspection stations intercepted 18% of pathogens, 14% of mites and 13% of insects. Mollusks were most commonly intercepted at marine ports (47%) and airports (36%). Plant inspection stations accounted for only 4% of all pest records but intercepted 48, 17 and 16% of mites, nematodes and mollusks, respectively.

Origin and taxonomic resolution of intercepted pests

We first summarized the number of interceptions of all pest taxa by continent or major world region of origin. The majority (57.1%) of the intercepted pests were from regions generally to the south of the U.S. including Central and South America (22.1% from 23 countries) and the Caribbean (18.4% from 39 countries including preclearance stations in Puerto Rico) (Table 1). North America, including Canada and Mexico, accounted for an additional 16.6% of the interceptions but nearly all of these pests (99.5%) originated in Mexico. Many pests also originated in Asia (16.4% from 30 countries), Europe (9% from 60 countries) and the Pacific Islands (9% from 36 countries including Hawaiian preclearance stations). Pests originating in Africa (4.1% from 55 countries), the Middle East (3.2% from 30 countries) and Australasia (0.8% from 12 countries) accounted for the remaining records. Country of origin was not identified for 2% of the interceptions, a situation that can occur when infested items were abandoned and not labeled.

Insects

Insects were consistently intercepted at much greater rates than other taxa (Table 1), comprising 73.5 to 84.6% of the interceptions each year (Figure 1). On average, there were 34,446 (SE ± 165.4) insect interceptions recorded in PIN annually. In 7031 of the records, largely represented by the Diptera, Lepidoptera, Heteroptera and Homoptera, the intercepted insect was identified only to order. This often occurred when only immature stages were recovered. The remaining 558,033 insect records represented a total of 10 orders, 211 families, 2321 genera and 2107 species (Figure 2). There were 155,547 insect records that were identified only to family, 177,425 insects were identified only to genus and 229,451 insects were identified to species. Homoptera was the most commonly represented order, accounting for 36.8% of all insect interceptions. The orders Lepidoptera and Diptera each contributed an additional 20.7% of the interceptions, while 13% of the intercepted pests were beetles in the order Coleoptera (Figure 2). At the family level, the orders Lepidoptera, Homoptera and Heteroptera were the most diverse, with 77, 40 and 32 different families, respectively, represented. Coleoptera, Lepidoptera and Homoptera were the most diverse at the genus level, where interception records included 766,463 and 423 different genera, respectively. Species diversity was greatest for the orders Coleoptera (626 species), Homoptera (502 species), Heteroptera (346 species) and Lepidoptera (272 species), which collectively accounted for 83% of the species diversity.

Because insects dominated the PIN data, trends in the origin of intercepted insects were generally similar to those for the entire database. Six regions accounted for nearly 90% of all insect interceptions including Central and South America (20.9% of insect records) the Caribbean (18.8%), North America (17%), Asia (13.6%), Europe (10.2%) and the Pacific Islands (8.5%) (Table 1). The frequency of insect interceptions from world regions or continents varied over time. Strong within-year periodicity was apparent for nearly all regions (Figure 3), which may reflect seasonal differences in commodity shipments, tourism or insect activity. Interceptions of insects originating in Central and South America

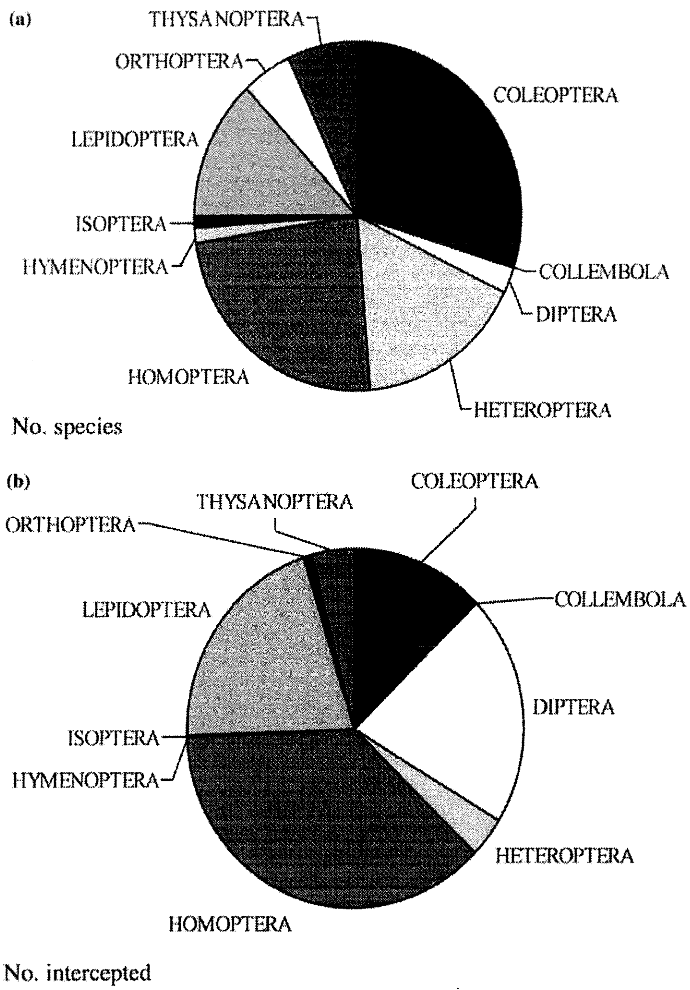

Figure 2. Number of (a) species represented by intercepted nonindigenous insects and (b) total intercepted insects, grouped by order.

increased consistently over the 17-year period, while interceptions from Europe remained relatively steady until the mid 1990's, when interceptions began to increase at a slow but observable rate. Insect interceptions from Caribbean countries, including preclearance stations in Puerto Rico, were generally high during the 17-year period, except for a notable drop that occurred in 1993–1996. Interceptions from Asia peaked in 1991–1992 and 1997, and then dropped in 1998–2000. Interceptions from North America (primarily Mexico) declined slightly through the 1990s, and then surged in 1999–2000. Interceptions from the Pacific Islands region declined in 1988 and have remained generally steady since then.

Insects originated in at least 259 locations, including predeparture stations in Puerto Rico and Hawaii (Table 3). Mexico, the most frequently recorded country of origin, accounted for 17% of all insect records in the PIN database (Table 3). Insects were often associated with fruit (mango, citrus and guava) and other produce, chestnuts (*Castanea* sp.), ornamental plants (e.g. *Chamaedorea* sp.), and cut flowers shipped from

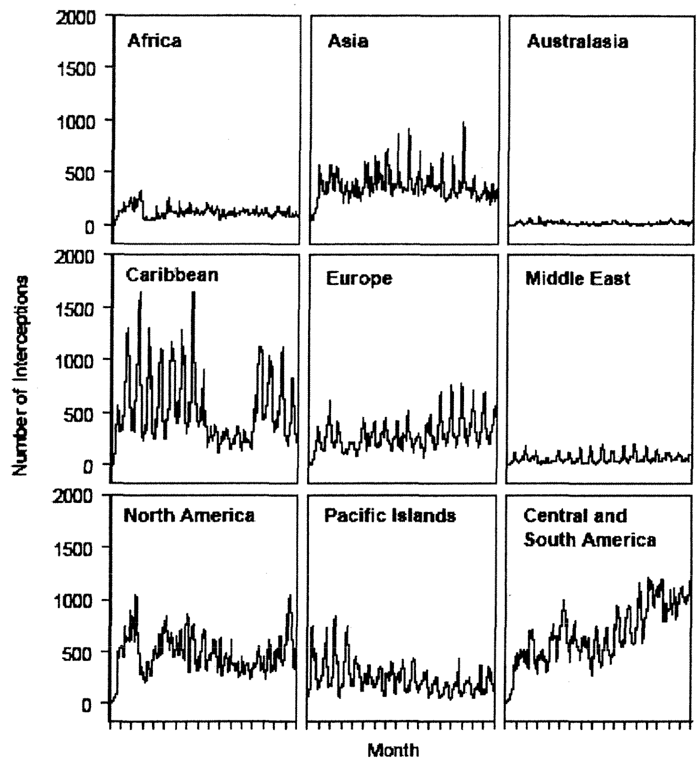

Figure 3. Time-series plot of the number of nonindigenous insects intercepted from major world regions or continents between 1984 and 2000.

Mexico, countries in Central and South America, Jamaica and the Netherlands. Hitchhiking insects were also commonly intercepted in shipments of tile and marble from Italy. Insects in the orders Homoptera, Lepidoptera and Coleoptera were collected from at least 230, 215 and 202 different locations, respectively. Insects in the orders Diptera, Thysanoptera, Heteroptera, and Hymenoptera originated in 182, 153, 145, 112 and 108 locations, respectively. Other orders of insects including the Orthoptera, Isoptera, Hymenoptera and Collembola, were collected from 42 to 94 locations. To identify notable increases or decreases in the number of insect interceptions from specific countries, we compared the relative proportion of insects intercepted in 1999–2000 to the proportion of insects originating in those countries in 1985–1986, for countries with a minimum of 1000 interceptions. The rate of insect interceptions from Peru increased most dramatically (41% higher in 1999–2000) followed by Vietnam (24%). Interceptions from several Central and South American countries also increased sharply including Ecuador (22%), the Dominican Republic (21%), Costa Rica (19%) and Nicarauga (18%). Insect interceptions from China and South Korea were each 15% higher. Countries with the greatest decrease in insect interceptions in 1999–2000 compared with 1985–1986 included South Africa (27%), West Germany (27%), Antigua and Barbados (22%), Tahiti (17%) the Philippines (15%) and Japan (13%).

Mites

Plant-feeding mites comprised less than 1% of the total records, averaging 0.8% (SE ± 0.11) of the interceptions annually (Table 1). There were 328 records recorded only as "mite" or resolved only to order, 2505 interceptions were identified

Table 3. Top 25 countries of origin of nonindigenous plants and plant pest taxa intercepted in the United States from 1984 to 2000.

Rank	Rank order by total interceptions	Percent of Total Records	Rank order by insect interceptions	Rank order by mite interceptions	Rank order by mollusk interceptions	Rank order by nematode interceptions	Rank order by pathogen interceptions	Rank order by weed interceptions
1	Mexico	16.25	Mexico	Costa Rica	Italy	Korea	Mexico	Jamaica
2	Puerto Rico	5.67	Puerto Rico	Mexico	Costa Rica	Mexico	Brazil	India
3	Hawaii	5.47	Hawaii	Guatemala	Israel	Ecuador	Puerto Rico	Iran
4	Jamaica	5.02	Colombia	Honduras	Spain	Netherlands	Philippines	Mexico
5	Colombia	4.50	Jamaica	Unknown	Netherlands	South Africa	Hawaii	Vietnam
6	India	3.26	Netherlands	Chile	Thailand	India	Dominican Republic	Thailand
7	Netherlands	3.11	Costa Rica	France	France	China	Taiwan	Taiwan
8	Dominican Republic	3.04	Dominican Republic	Netherlands	Nigeria	Poland	Hong Kong	China
9	Costa Rica	2.93	Italy	Dominican Republic	Greece	Peru	Thailand	El Salvador
10	Italy	2.77	Ecuador	El Salvador	Turkey	Japan	China	Unknown
11	Philippines	2.56	Guatemala	Germany	Puerto Rico	Chile	India	Ghana
12	Thailand	2.50	India	Jamaica	Hawaii	United Kingdom	Cook Islands	Nepal
13	Brazil	2.49	Thailand	Ecuador	Mexico	Italy	Argentina	Philippines
14	Guatemala	2.13	Korea	Japan	Africa	Philippines	South Africa	Myanmar
15	Ecuador	2.12	Japan	Colombia	Singapore	Thailand	Unknown	Hong Kong
16	Korea	1.88	Peru	Israel	Ghana	Hong Kong	Trinidad-Tobago	Pakistan
17	Japan	1.81	El Salvador	Italy	Portugal	Vietnam	Vietnam	Honduras
18	El Salvador	1.75	Haiti	United Kingdom	Europe	West Germany	American Samoa	Korea
19	Peru	1.68	Philippines	China	Australia	Spain	Japan	Guatemala
20	Unknown	1.67	Brazil	Korea	Unknown	Israel	Costa Rica	Malaysia
21	Haiti	1.63	Unknown	India	Colombia	Australia	Netherlands	Haiti
22	Vietnam	1.51	Nigeria	South Africa	China	Colombia	Jamaica	Singapore
23	Nigeria	1.36	Chile	Spain	Japan	Guatemala	Australia	Laos
24	Iran	1.16	Vietnam	Russian Federation	Honduras	Argentina	Singapore	Nigeria
25	Taiwan	1.13	Honduras	Australia	Dominican Republic	Costa Rica	Guatemala	Trinidad–Tobago

to family, 2801 were identified to genus and 463 were identified to species. At least 13 families, 44 genera and 38 species of mites were included in the database. The majority of the intercepted mites were either spider mites in the family Tetranychidae (59.7%) or mites in the family Tarsonemidae (23.5%). Central and South American countries accounted for 50% of the mite interceptions while European countries accounted for additional 15% of the records (Table 1). Mites were intercepted from 113 different origins. Mites were frequently associated with ornamental plants (*Codiaeum* sp., *Cordyline* sp.) fruit (*Malus* sp.), plant propagative material, and cut flowers (Table 2) originating in Costa Rica (18%), Mexico (16%) Guatemala (12%) and Honduras (9%) (Table 3).

Mollusks

Interceptions of mollusks accounted for 0.7 to 3.0% of all records annually (Table 1). Mollusk interceptions generally increased over time, with more than 1000 interceptions recorded annually from 1998 to 2000 (Figure 1). There were 172 interceptions identified broadly as mollusk, 482 interceptions identified only to family level, 2544 interceptions identified only to genus and 8565 interceptions identified to species. Interceptions represented at least 32 families, 88 genera and 125 different species. More than half of the mollusks that were intercepted originated in Europe (55%), with Central and South America (14%), the Middle East (9%), Asia (8%) and Africa (6%) accounting for the remainder (Table 1). At least 126 locations were recorded as the origin for mollusk interceptions. Italy, however, accounted for 33% of the mollusk interceptions, many of which were associated with shipments of ceramic tiles. Other common countries of origin included Costa Rica, Israel and Spain, accounting for 10.4, 8.5 and 7.6% of mollusk records, respectively (Table 3). In addition to tiles, mollusks were often found "at large" in shipping containers or baggage, or associated with shipments of plants, cut flowers and marble.

Nematodes

Nematodes accounted for less than 0.1% of the records overall and in any year (Table 1). Nematodes originated principally in Asia (35%), Europe (21%) and Central and South America (19%) (Table 1). The most common countries of origin for nematodes were Korea (15%) and Mexico (9%). Nematodes were also intercepted from at least 68 other countries. Most nematodes were recovered from soil or plant propagation material (Table 3) or associated with plants such as ginseng (*Panax* sp.).

Pathogens

Plant pathogens comprised 10.2 to 17.2% of records annually (Table 1). There were 4000 to 7500 interceptions per year until 2000, when 8097 pathogens were recorded. Plant pathogen interceptions represented at least 119 different families and 252 different genera. Not all species names could be verified but records represented at least 260 different pathogen species. Roughly 10% of the interceptions were identified only as pathogen. The fungal genera *Cercospora* sp. and *Elsinoe* sp. and the bacterium *Xanthomonas* sp., each included at least 10% of the pathogen interceptions. Other common genera included the fungi *Puccinia* sp., *Guignardia* sp., *Mycosphaerella* sp., *Phoma* sp., *Phomopsis* sp., *Phyllosticta* sp., and *Uromyces* sp., each with at least 4% of the pathogen records. Pathogen interceptions were often associated with ornamental plants and propagative material (*Eryngium* sp. and *Alysia* sp.)., fruit (especially citrus) and cut flowers (Table 3). Common origins of plant pathogens included countries in Asia (21% of pathogen records), Central and South America (17%), the Pacific Islands (17%) and the Caribbean (16%) (Figure 4), as well as North America (primarily Mexico). Over the 17-year period, pathogen interceptions from North America (mostly Mexico) increased most notably, while interceptions on material from Central and South America declined (Figure 4). Strong within-year periodicity was apparent for pathogen interceptions from most world regions or continents (Figure 4). In addition to Mexico, which accounted for 20% of all pathogen records, pathogens were intercepted from at least 186 other locations. Brazil, Puerto Rico, and the Philippines each accounted for roughly 8% of the pathogen records (Table 3). Substantial increases in the relative proportion of pathogen interceptions in 1999–2000 compared with 1985–1986 occurred for Mexico (29% higher in 1999–2000), China (26% higher), Vietnam

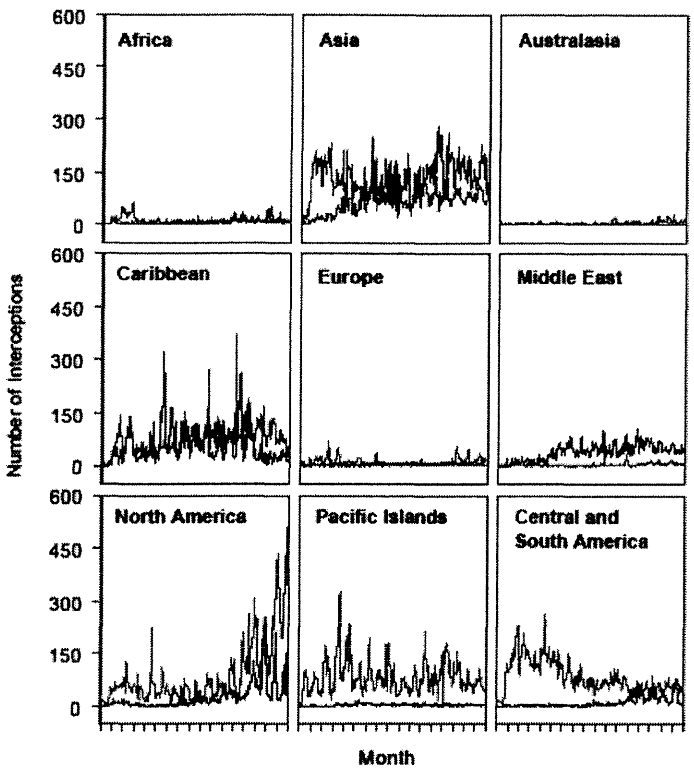

Figure 4. Time-series plot of the number of nonindigenous plant pathogens (blue) and weeds (black) intercepted from major world regions or continents between 1984 and 2000.

(24% higher), and preclearance stations in Puerto Rico (17% higher). The relative proportion of plant pathogen interceptions decreased most notably for Taiwan (Republic of China) (25% lower in 1999–2000), Argentina (18% lower), Japan (13% lower), South Africa (12% lower) and India (12% lower).

Weeds

Annually, interceptions of weed species accounted for an average of 6.5% (SE ± 0.69) (Figure 1) of all records, ranging from 1.2% in 1984 to 9.6% in 1995 (Figure 1). The PIN records included 76 interceptions identified broadly as Magnoliophyta, 2 interceptions identified only as Fabaceae, 9135 interceptions identified only to genus and 41,033 interceptions identified to species. Records of weed interceptions represented a total of 31 families, 70 genera and 54 different species. Asian countries accounted for 41% of the weed records and interceptions generally increased over the 17-year period (Figure 4). Countries in the Caribbean accounted for 22% of the weed records but interceptions were notably lower in 1996–2000 than in previous years. North America (primarily Mexico), Middle Eastern countries and some Central and South American countries became increasingly common sources of intercepted weeds (Figure 4). Weeds originated in 155 locations, with Jamaica (22%), India (16%), Iran (14%) and Mexico (10%) collectively accounting for the majority of all weed interceptions (Table 3). Weed interceptions from nearly all of the major source countries increased steadily over the 17-year period. The relative proportion of weed interceptions in 1999–2000 compared with 1985–1986 increased most markedly for El Salvador (35% higher in 1999–2000), Mexico (26% higher), Vietnam (20% higher) and India (17% higher). Intercepted weeds were most often recovered as contaminants in baggage but were also frequently associated with edible seeds, spices, grains or other plants including *Cuminum* sp., *Solanum* sp. and *Oryza* sp. (Table 2). Weeds were also frequently associated with grains, fruit and non-agricultural items carried by travelers (Table 2).

Inspection stations

There were 167 ports of entry, land border crossings and preclearance stations where APHIS PPQ inspections occurred from 1984 to 2000, but 95% of the pest interceptions occurred at only 30 of those sites (Table 4). Most of the ports intercepting large numbers of each taxa were located on the east or west coasts or on the U.S.-Mexico border. Three stations that handle high volumes of cargo and travelers, including Miami, Florida (airport and marine port), JFK International Airport in New York, and Los Angeles, California (airport and marine port), accounted for 43.1% of all interceptions. Inspection stations along the U.S.-Mexico border, primarily in Texas, intercepted more than 15% of all pests. Pre-clearance stations in Honolulu, Hawaii and San Juan, Puerto Rico recorded an additional 16.3% of the interceptions. Only four interior ports, Chicago and Des Plaines IL, Philadelphia, PA and Detroit, MI, individually accounted for 0.45% or more of the pest records. Roughly 27% of the 5042 port-origin combinations in the PIN database represented instances of a single pest record from an individual country of origin that was intercepted at particular inspection station.

Table 4. Inspection stations including ports-of-entry and border crossings with 2000 or more interceptions of nonindigenous plants or plant pests from 1984 to 2000.

Station	State	Insects	Mites	Mollusks	Nematodes	Pathogens	Weeds	Total	Percent of total records
Miami	FL	117,498	2800	3305	44	5469	2122	131,238	18.00
J.F.K. Int. Airport	NY	71,624	657	2051	50	10,451	14,855	99,688	13.67
Los Angeles	CA	52,666	151	417	85	19,061	11,244	83,624	11.47
Honolulu1	HI	48,965	1	145		11,675	1291	62,077	8.52
San Juan1	PR	45,846	12	383	1	10,212	6	56,460	7.74
Houston	TX	21,722	452	1100	28	1476	3188	27,966	3.84
Laredo	TX	17,125	39	54	8	5827	3120	26,171	3.59
El Paso	TX	19,054	829	8	6	4659	850	25,408	3.49
San Francisco	CA	9436	80	400	39	5107	1750	16,812	2.31
Dallas	TX	12,681	381	72	2	347	2485	15,968	2.19
Brownsville	TX	11,285	30	5	10	2018	616	13,964	1.92
San Diego	CA	11,699	40	20		125	14	11,898	1.63
Des Plaines	IL	11,335	4	53	4	255	153	11,804	1.62
Atlanta	GA	8437	23	62	3	997	1738	11,260	1.54
Seattle	WA	7344	58	81		2660	435	10,587	1.45
Chicago	IL	9639	62	66	17	516	136	10,436	1.43
Fort Lauderdale	FL	10,221	8	32		45	29	10,335	1.42
New Orleans	LA	5719	15	444	66	1857	1446	9547	1.31
Nogales	AZ	8551	4	3	2	830	144	9534	1.31
Elizabeth	NJ	5107	16	170	12	1262	1800	8367	1.15
Boston	MA	5700	3	141	2	89	80	6015	0.83
Hidalgo	TX	4898	17	3		779	82	5779	0.79
Anchorage	AK	4960	15	7	1	450	25	5458	0.75
Baltimore	MD	3602	18	188	1	129	186	4124	0.57
Philadelphia	PA	2582	286	38		324	398	3628	0.50
Detroit	MI	2380	1	52		76	371	3330	0.46
Port Orlando	FL	2162	20	25		831	197	3235	0.44
Eagle Pass	TX	894	6	1		2232	62	3195	0.44
Erlanger	KY	2232	14	32	2	85	483	2848	0.39
Savannah	GA	2160		456		163	34	2183	0.39
Total		537,974	6042	9814	383	90,007	49,340	693,561	95.14

Strong regional associations in the point of origin of pest interceptions were evident at major ports (those that intercepted at least 3% of all pests). Inspection stations in Florida, California, New York, Texas and the U.S. territory of Puerto Rico, for example, each accounted for more than 5% of all interceptions and each was linked with a different assemblage of pest origins (Figure 5). Pest interceptions in Texas predominantly originated in neighboring Mexico, while the majority of pests intercepted at stations in Florida and Puerto Rico originated in Central and South America or the Caribbean. The source pool of pests intercepted in New York and California were more diverse. At J.F.K. International Airport and other New York stations, relatively high numbers of intercepted pests originated in the Caribbean, Europe, Africa, Asia and the Middle East. California stations intercepted relatively high numbers of pests that originated in Asia, but also frequently detected pests from Mexico, the Pacific Islands and Central and South America. Central and South American countries accounted for at least 5% of the interceptions at all of the top five states.

Figures 6a–6f depict the relative importance of countries as "pest donors" in terms of the number and taxonomic richness of intercepted pests and the number of U.S. ports or border crossings where pests from individual countries were intercepted. In this analysis, limited to pathways with 5000 or more pest interceptions, larger circles correspond to countries that were the source of pests intercepted at many ports or border crossings. Similarly, small circles correspond to countries that were the source of pests intercepted at only a few inspection stations.

These figures highlight two patterns of invasion pathways linked to foreign trade. First, the log of taxa richness generally increased linearly with the log number of interceptions for each of the major commodity pathways in cargo and baggage. Secondly, countries that were frequently recorded as the origin of pests were likely to send commodities through numerous ports, while commodities from countries that were infrequently

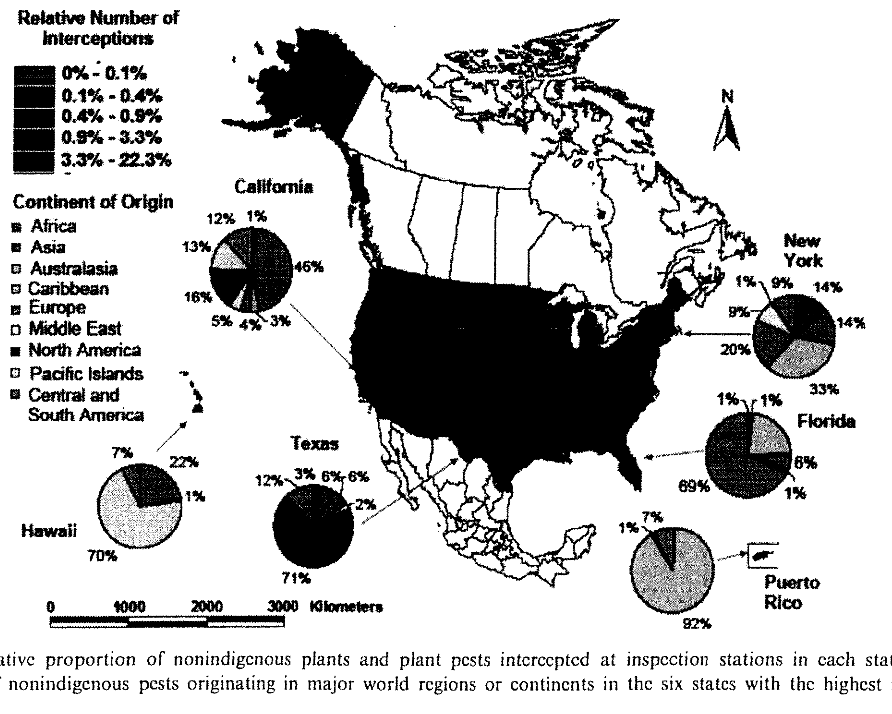

Figure 5. Relative proportion of nonindigenous plants and plant pests intercepted at inspection stations in each state and the proportion of nonindigenous pests originating in major world regions or continents in the six states with the highest number of interceptions.

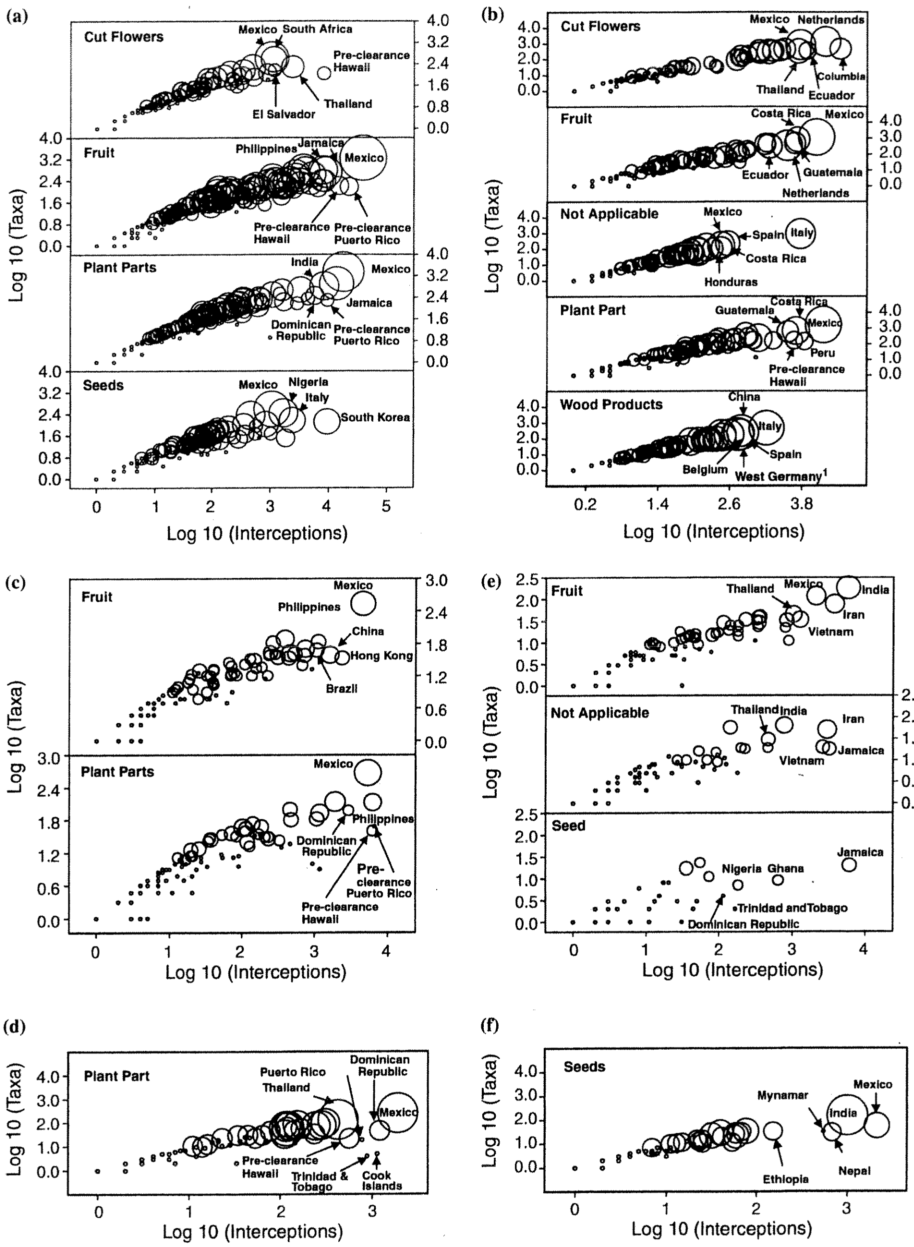

Figure 6. Number of nonindigenous pest interceptions (log 10 transformed) in relation to species richness (log 10 transformed) for commodity pathways with 5000 or more pest interceptions from 1984 to 2000. Number of inspection stations intercepting pests from individual countries of origin were grouped into ten classes represented by the size of the circles, where the largest circles represent 45–50 stations and smallest circles represent 1–5 stations. Plots represent insects intercepted in (a) baggage and (b) cargo, pathogens intercepted in (c) baggage and (d) cargo, and weeds intercepted in (e) baggage and (f) cargo.

listed as countries of origin arrived at relatively few ports. Countries with large numbers of port-origin nodes for individual commodities (e.g. the large circles in the upper right corner of the plots), therefore, may represent pathways of primary concern. These countries served as a source pool of a large and diverse assemblage of pests that arrived at many ports or border crossings throughout the United States. Figures 6a–6f also illustrate the extent of variation in pest interceptions among commodities imported from various countries. For example, the Netherlands was a major source of insects arriving on fruit shipped as cargo (15,513 insects) but insects were rarely intercepted on fruit carried in baggage by passengers from the Netherlands (484 insects). In contrast, Mexico was consistently a major source of insects intercepted both in cargo and baggage pathways.

Discussion

The PIN database provides evidence of the extent of human-mediated transport of plant pests and weeds from around the world to the United States. Most of the interceptions occurred at airports where pests were recovered from fruit, plants, spices and other materials brought by travelers disembarking from international flights. Frequent interceptions were also associated with some imported commodities such as cut flowers, which are shipped almost exclusively by air and often carry a suite of specialized or hitchhiking pests. Because APHIS PPQ inspection protocols are not based on randomized sampling and negative inspections are not recorded, PIN data cannot be used in a predictive manner to estimate the actual abundance, diversity or frequency of nonindigenous plant pest arrival. We also cannot know what proportion of the nonindigenous plant pests that arrived at U.S. borders were intercepted by inspectors. High risk commodities, primarily items known to be associated with frequent or abundant pest interceptions, may receive extra attention from inspectors, perhaps increasing the proportion of pests intercepted on those commodities compared to a purely random sample. In addition, potential introductions of nonindigenous species are likely reduced by mandatory pest mitigation measures or inspections conducted in foreign countries before specific agricultural commodities can be shipped to the U.S. (Cavey 2003; Work et al. 2005).

Nevertheless, an impressive array of nonindigenous organisms from around the world is transported to the U.S. every year via international trade and travel. More than half of the pests recorded in PIN were associated with small parcels and baggage carried by travelers. Pests arriving with cargo, however, may represent a greater risk and may be more difficult to detect than pests in baggage. Much of the cargo that arrives at U.S. ports and borders is shipped further, often to multiple destinations in the U.S., potentially increasing the chance that nonindigenous organisms may encounter suitable hosts or climatic conditions. In 2000, the U.S. imported agricultural commodities valued at $38 billion (Haack 2001; US Bureau of the Census 2001), but APHIS personnel are able to examine no more than 2% of the agricultural commodities that enter the U.S. as cargo and that are targeted for inspection (NRC 2002; Cavey 2003). While this inspection rate has remained relatively stable for the past 25 years, finding pests in cargo is not easy. Cargo is increasingly shipped in large containers that can be difficult to inspect thoroughly because of dark or poorly ventilated conditions (Stanaway et al. 2001). Unlike items carried in baggage which can usually be confiscated and examined later when time permits, cargo inspections must be completed efficiently to ensure that produce or similar commodities arrive at their final destinations on time and in suitable condition for sale. Moreover, in addition to pests transported in baggage and cargo, an unknown number of organisms are undoubtedly introduced when produce or other commodities are smuggled into the United States. Thus the interception records in PIN likely represent a conservative estimate of the amount and variety of nonindigenous species arriving in the United States.

While arrival in a new habitat is the first step in the invasion process, nonindigenous species are challenged by environmental and demographic stochastic forces that must be overcome if the species are to become established and persist (NRC 2002). Estimates of establishment rates of nonindigenous organisms range from 2% of accidentally introduced species to 65% of species intentionally introduced in biological control programs (Bierne 1975; Hall and Ehler 1979; Crawley 1986; van Lenteren 1995; Grevstad 1999a; Kiritani and Yamamura 2003). Establishment rates may be especially low for species subject to strong Allee effects, assuming that most introductions are comprised of relatively few colonists or propagules (Hopper and Roush 1993; Lewis and Kareiva 1993; Courchamp et al. 1999; Grevstad 1999b; NRC 2002; Liebhold and Bascompte 2003). Work et al. (2005), however, using data from a randomized cargo sampling protocol recently implemented by APHIS, predicted that with an establishment rate of only 2%, 42 new species of nonindigenous, phytophagous insects transported to the U.S. in cargo may have become established in the U.S. between 1997 and 2001. Whether this prediction is accurate remains to be seen. It is clear, however, that continuing increases in global trade and travel will provide opportunities for nonindigenous species to be transported into the U.S. at rates that are unprecedented in world history.

Although the PIN database documents interceptions of six major taxa, the records were dominated by insects in every year. This is not surprising given the abundance, diversity and relatively high mobility of insects (Southwood 1984). Not only can many different insect species infest most plants and produce, traits such as the ability of insects to tolerate unfavorable conditions in diapause or other quiescent states enable many species to hitchhike on commodities with which they would not otherwise be associated. Further, even insects that are very small, cryptic or live under bark or in other hidden locations may be easier for inspectors to detect than other taxa such as plant pathogens. Plants or produce infected with pathogens may not exhibit diagnostic symptoms or signs of infection when they arrive and even suspect specimens may still require relatively sophisticated equipment or methods for identification. The array of nonindigenous plants arriving in the U.S. is undoubtedly underestimated, as well. Only plant species that are currently included on the U.S. Federal Noxious Weed or Seed lists are recorded in PIN; as of 2004, this included only 19 aquatic plants, 70 parasitic plants and 72 terrestrial plant species (USDA Federal Register 2004). A more comprehensive estimate of the frequency and diversity of nonindigenous plants, particularly those introduced as contaminants in cargo, would likely require a substantial increase in inspection efforts by APHIS personnel.

Patterns in the origins of pests recorded in PIN reflect a combination of factors including trade policies between the U.S. and other countries, trends in tourism, changes in market demand and supply, specific pest mitigation efforts by exporters and revisions in APHIS policies and personnel. Underlying reasons for these patterns can sometimes be derived from economic or political trends associated with specific countries. Haack (2001), for example, reported that the number of scolytid beetle interceptions from foreign countries was related to the value of imports from those countries. Similarly, Liebhold et al. (2006) showed that the number of insect pests intercepted in baggage from a given country was positively related to the number of travelers arriving in the U.S., but inversely related to the country's gross national product.

Normalization of relations and increased trade between the U.S. and countries such as Vietnam and China were mirrored by notable increases in pest interceptions over time. Potential introductions of plant pests or weeds from China have recently received particular attention from scientists in the U.S. and Canada due in part to the dramatic increases in trade between the U.S. and China (US Census Bureau 2001; USDA ERS/FATUS 2001; NRC 2002) and publicity associated with discovery of notorious pests such as the Asian longhorned beetle (*Anoplophora glabripennis* (Motchulsky)) (Haack et al. 1997). In terms of total pest interceptions recorded from 1984–2000, China was only the 35th most common origin of all pests and the 42nd most common origin of intercepted insects. Interceptions of insect pests and plant pathogens from China were, however, roughly ten-fold more common from 1995 to 2000 than from 1985–1990. Other changes in interception rates from a specific country may be strongly influenced by a single commodity. For example, imports of asparagus from Peru jumped from less than 2000 metric tons in 1990 to more than 30,000 metric tons in 2000 (USDA FAS 2004).

Insect interceptions, which comprised 96% of all Peruvian pest records, increased from 242 records in 1990 to 3167 records in 2000.

Differences in the number of pest interceptions originating in Mexico and Canada, the top trading partners of the U.S., were notable. Mexico was the most common origin of all intercepted pests, while Canada was the source of less than 0.5% of the intercepted pests. This pattern may be due in part to the high degree of similarity between U.S. and Canadian fauna. Most organisms associated with Canadian commodities are already established in the U.S. and would not be considered pests of regulatory significance or recorded in the PIN database. Recently intensified concerns of APHIS about organisms such as bark beetles and agricultural plant pathogens entering the U.S. from Mexico may also be reflected in the jump in pest interceptions recorded in 1999–2000.

The applicability of PIN data to address specific questions related to invasion ecology will depend on the organisms or situation of interest. Use of PIN data for statistically robust comparisons or predictions will generally be inappropriate because of non-random nature of the sampling and because inspection protocols and intensity tend to vary over time and among locations and individuals. In addition, input from experienced APHIS personnel who are knowledgeable about the intricacies of inspections and data collection is critical for accurate interpretation of PIN data. Without such assistance, it would be easy to arrive at erroneous conclusions. Liebhold et al. (2006) present an example of one previously published analysis where interceptions of the Mediterranean fruit fly in the PIN data were interpreted incorrectly. Considerable effort and expertise were also needed to check and sometimes correct taxonomic assignments and typographical errors in some PIN records.

Despite these limitations, the PIN data provide a valuable historical record of the patterns in the origins, commodities and locations associated with frequent interceptions of nonindigenous pests. These patterns can be used to identify high-risk invasion pathways and delineate organism–commodity associations of concern. Such information can be used to focus inspector training and detection efforts. At a finer scale, identification of links among pests on individual commodities, countries and ports of entry can help APHIS and trade officials develop mitigation strategies to decrease the rate of arrival and the risk of establishment of specific pests. The extent of the information included in PIN for many insects, mollusks and other taxa is substantial and may be useful in case studies of specific organisms (Haack 2001; Marshall et al. 2003; Liebhold et al. 2006).

The PIN database may also be valuable for monitoring trends in pest interception rates over time, as new regulations or policies are implemented. Recent changes in federal government structure transferred most of the APHIS inspectors stationed at U.S. ports of entry and border crossing to the U.S. Department of Homeland Security (DHS). The two agencies now share responsibility for excluding nonindigenous plant pests. Under the new structure, most inspection duties, except for propagative material inspections, will be performed by DHS personnel, while APHIS personnel will provide direction and support. Both agencies will continue to use the PIN database, expected to be renamed as the Pest Interception Database (PestID), to monitor pest risk in import pathways. The economic and environmental impacts that nonindigenous pests have had on natural resources and agriculture in the U.S., combined with expected increases in global trade and travel, suggest that the need for pest survey and detection efforts is not likely to diminish.

Acknowledgements

We thank the USDA APHIS PPQ for access to the PIN 309 data and we extend our appreciation to the many inspectors and identifiers who collected the data recorded in PIN 309. We acknowledge the constructive and insightful suggestions provided by Sarah Reichard, University of Washington and Sue Tolin, Virginia Polytechnic University at the genesis of this project and thank Jane Levy, USDA, APHIS, PPQ, Riverdale, Maryland for reviewing an earlier draft. This work was conducted as part of the Invasion Pathways Working Group, supported in part by the National Center for Ecological Analysis and

Synthesis, funded by NSF Grant No. DEB-0072909, and the University of California, Santa Barbara campus. Additional support was provided by the USDA Forest Service, and the Michigan Agricultural Experiment Station Project No. MICL01700 at Michigan State University.

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