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An Analysis of Arthropod Interceptions by APHIS-PPQ and Customs and Border Protection in Puerto Rico

DAVID A. JENKINS, RUSSELL F. MIZELL, III, SKIP VAN BLOEM, STEFANIE WHITMIRE, LEYINSKA WISCOVITCH, CRYSTAL ZALESKI, AND RICARDO GOENAGA

ABSTRACT: USDA Animal Plant Health Inspection Service Plant Protection and Quarantine (APHIS-PPQ) and Customs and Border Protection (CBP) inspect traffic entering the United States for arthropods posing a threat to national agriculture or ecosystems. We analyzed interceptions made by these agencies in Puerto Rico and the U.S. Virgin Islands between October 2006 and December 2009 for patterns with regard to the frequency of interceptions, origins of interceptions, and the taxa intercepted. 6,952 arthropods were intercepted in freight or luggage entering Puerto Rico and the U.S. Virgin Islands from foreign countries and 9,840 arthropods were intercepted from freight or luggage leaving Puerto Rico or the U.S. Virgin Islands destined for mainland U.S. Most (77%) of the arthropods intercepted entering Puerto Rico were intercepted in freight or luggage originating within the Caribbean. Most intercepted arthropods were in the order Hemiptera (52% of all interceptions), followed by Diptera (16%), Coleoptera (10%), Lepidoptera (8%), Thysanoptera (5%), Acari (4%), and Hymenoptera (2%). Intercepted arthropods from foreign countries were more equitably spread among orders, whereas 89% of the arthropods intercepted from Puerto Rico and the U.S. Virgin Islands were in the orders Hemiptera and Diptera. Hemiptera made up 28% of the interceptions from foreign countries, but 69% of the interceptions made from Puerto Rico and the U.S. Virgin Islands. Only 7 of 28 adventive arthropods recently established in Puerto Rico were intercepted during this study, and these were intercepted at relatively low frequency (between 3 and 132 interceptions; mean of 35 interceptions). We present data suggesting that most adventive arthropods that occur in both Puerto Rico and Florida established in Florida first, likely due to less stringent or non-existent import inspections for traffic coming into Puerto Rico from the U.S. Finally, we highlight several adventive arthropods that have recently established in Puerto Rico and discuss what we can learn from these invaders.

KEYWORDS: invasive arthropods, dispersal, Caribbean, interception, Florida

The increased mobility of both humans and goods has resulted in an increase in the spread of adventive (non-indigenous) organisms (Carlton and Geller 1993; see Miller 1994), some of which negatively affect agriculture or the environment. Recent high-profile invasive arthropods that have established in North America include the bean plataspid, *Megacopta cribraria* (Eger et al. 2010), the emerald ash borer, *Agrilus planipennis* (Coleoptera: Buprestidae) (EAB INFO 2011), the Asian longhorned beetle, *Anoplophora glabripennis* (Coleoptera: Cerambycidae) (Haack et al. 1997), the brown marmorated stinkug, *Halyomorpha halys* (Hemiptera: Pentatomidae) (Hoebeke and Carter 2003), and the redbay ambrosia beetle, *Xyleborus glabratus* (Coleoptera: Curculionidae)(Rabaglia et al. 2006). According to the definitions in Frank and McCoy (1995), none of these arthropods were purposely introduced; all are immigrants, arriving of their own volition, most as stowaways on cargo.

Governments have acted to exclude adventive organisms from their countries using barriers, including inspection and quarantine of incoming traffic and commodities and trade restrictions on commodities that may harbor adventive species. The *Plant Quarantine Act*, enacted in 1912, was the first significant legislation in the U.S. providing a federal inspection and quarantine system to protect North American agriculture from adventive pests. The United States Department of Agriculture (USDA) Animal and Plant Health Inspection Service (APHIS) Plant Protection and Quarantine (PPQ) program is the agency responsible for keeping adventive arthropods from entering the United States. Since 2001 and the formation of the Department of Homeland Security, Customs and Border Protection (CBP) also performs these duties.

Puerto Rico has an odd relationship with the United States. Although APHIS-PPQ and CBP operate in Puerto Rico, their role is to safeguard Puerto Rico from potential adventives coming from foreign countries (these inspections are conducted by CBP Agricultural Specialists) *and* to safeguard mainland agriculture and natural resources from potential adventives in Puerto Rico (these inspections are conducted by APHIS-PPQ Technicians and Officers). The Puerto Rico Department of Agriculture has the task of protecting Puerto Rico from adventive pests, but it has very limited authority in this regard. As such, no agency inspects traffic coming into Puerto Rico from the mainland U.S. as is the case in Hawaii, for example. In some ways, regulatory agencies consider Puerto Rico and the Virgin Islands as outposts. There have been proposals of quarantine facilities with the intention of studying adventive arthropods in Puerto Rico prior to their arrival on the mainland.

Puerto Rico's mild climate, diverse flora, and geographical location in the Caribbean make it ideal for adventive invaders. For example, there are approximately 500 species of tree native to Puerto Rico and the Virgin Islands (Little and Wadsworth 1974), and 118 exotic trees reproducing in Puerto Rico (Francis and Liogier 1991). The exotic tree species are often the most abundant trees, including *Mangifera indica* (Anacardiaceae), *Spathodea campanulata* (Bignoniaceae), and *Leucaena leucocephala* (Fabaceae).

Methods

Human traffic is a key mode of dispersal for many invasives, so we decided to analyze the arthropods intercepted in Puerto Rico by APHIS-PPQ and CBP for patterns that would help predict future invaders and aid in risk assessment. Particular patterns we were looking for were the origins of interceptions; the distribution of interceptions among taxa (which, if any, taxa are more likely to be intercepted); and the frequency of interceptions.

An interception is each time a species is found on material being imported or exported from Puerto Rico, not the number of individuals found within a shipment. Thus, the inspection of one shipment that is infested with 10 arthropod species would have 10 interceptions regardless of whether there was one individual of each species found, or thousands of each species. It is reasonable to expect that interception frequency is related to the probability of a taxon becoming established, and this has become known as "propagule pressure" (Carlton 1996; Lockwood et al. 2005). It is difficult to test whether interception frequency is correlated to establishment, but we can look at the frequency with which established arthropods were intercepted during the study.

Because APHIS-PPQ inspects traffic leaving Puerto Rico for the mainland U.S. and CBP inspects traffic entering Puerto Rico from foreign countries, we are able to conduct a valuable comparison between arthropods intercepted leaving Puerto Rico and arthropods entering Puerto Rico.

Ideally, we would have liked to analyze many more years of data, but extracting these data from the database into a form which could be analyzed was exceedingly painstaking. If the form of data storage has not already been changed, we recommend that APHIS-PPQ do so in order to more rapidly evaluate trends in interceptions and respond to them.

One caveat should be noted: These data represent data from the San Juan APHIS-PPQ work unit only. Important ports such as Ponce, Mayaguez, and Aguadilla are not represented in this data set. The interceptions represent only some of the ways that arthropods can move from one place to another. Important avenues, including private vessels or natural dispersal, are not included in this analysis.

Results

Origins of interceptions. Between October 2006 and December 2009, 6,952 arthropods were intercepted by CBP and 9,840 arthropods were intercepted by APHIS-PPQ. In theory, all interceptions made by CBP should be arthropods entering from foreign countries and all PPQ interceptions should be arthropods intercepted leaving Puerto Rico or the U.S. Virgin Islands for the mainland U.S. This is the case for 98% of the CBP interceptions and 97% of the interceptions made by PPQ during our survey. 77% of all interceptions made by CBP were in traffic originating in the Caribbean. Ten countries accounted for 82% of all interceptions made by CBP (Table 1). The following six countries accounted for 75% of all interceptions made by CBP.

Table 1. The thirty countries accounting for more than 95% of all interceptions made by CBP during the study. In total, 6,952 interceptions were made by CBP during the study.

Country	Interceptions
Colombia	2,500
Dominican Republic	811
Dominica	532
Canada	425
Costa Rica	349
Ecuador	250
St. Lucia	169
Grenada	114
Antigua	140
Tortola	86
China	82
Italy	74
St. Kitts	71
St. Vincent	99
Peru	61
Aruba	58
Spain	51
Trinidad and Tobago	43
Turkey	40
St. Maarten	27
India	24
Brazil	23
Mexico	23
Nevis	20
Nicaragua	18
Anguilla	17
British Virgin Islands	17
Panama	17
Guadaloupe	16
Haiti	14

Colombia. Interceptions on traffic originating in Colombia accounted for 39% (2,500 interceptions) of all interceptions from foreign countries and 22% of all interceptions from Colombia were thrips in the genus *Frankliniella.* More than 98% of interceptions from Colombia were on cut flowers.

Dominican Republic. Interceptions on traffic originating in the Dominican Republic accounted for 13% (811 interceptions)

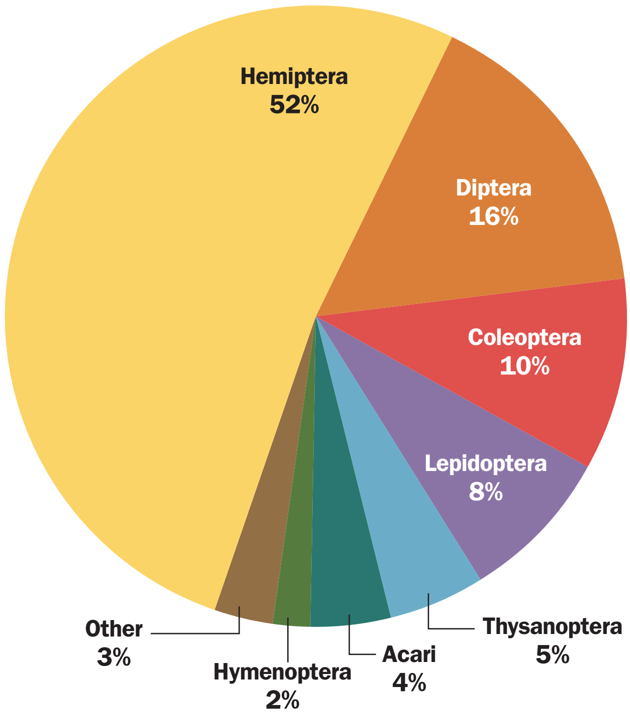

Fig. 1. Arthropod orders intercepted

of all interceptions from foreign countries, and more than 99% of this was from fruits and vegetables, particularly peppers (*Capsicum* spp. [Solanaceae], 222 interceptions), citrus (*Citrus* spp. [Rutaceae],192 interceptions), avocado (*Persea americana* [Lauraceae], 124 interceptions) and sweet potato (*Ipomoea batatas* [Convolvulaceae], 88 interceptions).

Dominica. Interceptions on traffic originating in Dominica accounted for 8% (532 interceptions) of all interceptions from foreign countries. Interceptions from Dominica were primarily on vegetables and fruits, with 90 interceptions on mango (*Mangifera indica* [Anacardiaceae]), 86 interceptions on thyme (*Thymus vulgaris* [Lamiaceae]), 41 interceptions on chives (*Allium schoenoprasum* [Lilliaceae]), and 31 interceptions on *Nasturtium* species [Brassicaceae].

Canada. Interceptions on traffic originating in Canada accounted for 7% (425 interceptions) of all interceptions from foreign countries. 79% of all interceptions made from Canada were on Christmas trees (*Abies* spp.[Pinaceae]) imported in November and December.

Costa Rica. Interceptions on traffic originating in Costa Rica accounted for 5% (349 interceptions) of all interceptions from foreign countries, mostly from fruits and vegetables. 89 interceptions were made on cabbage (*Brassica* spp.[Brassicaceae]), 80 interceptions on chayote (*Sechium edule* [Cucurbitaceae]), 75 interceptions on pineapple (*Ananas comosus* [Bromeliaceae]), and 33 interceptions on *Eryngium foetidum* [Apiaceae].

Ecuador. Interceptions on traffic originating in Ecuador accounted for 4% (250 interceptions) of all interceptions from foreign countries, mostly fruits, vegetables and cut flowers.

Taxa intercepted. Seven orders accounted for 97% of the intercepted arthropods during this study. Most arthropods intercepted (52%) were in the order Hemiptera (Fig. 1). Other orders intercepted included Diptera (16%), Coleoptera (10%), Lepidoptera (8%), Thysanoptera (5%), Acari (4%), and Hymenoptera (2%) (Fig. 1). Most of these are large orders with many species worldwide, accounting for the frequency of their interception during this study. The taxa intercepted entering Puerto Rico from foreign countries varied in frequency from the taxa intercepted leaving Puerto Rico.

Table 2. Frequency of actual interceptions from foreign countries by order and the expected frequency based on the proportion of the worldwide fauna that these make up (based on Triplehorn & Johnson 2005).

Order	Observed	Expected
Protura	0	4.06
Diplura	0	6.49
Thysanura	2	5.68
Collembola	64	48.69
Dermaptera	10	14.61
Orthoptera	45	162.31
Isoptera	13	18.67
Embioptera	0	1.62
Psocoptera	64	24.35
Phthiraptera	0	25.97
Ephemeroptera	0	16.23
Odonata		40.58
Neuroptera	8	44.63
Trichoptera	2	56.81
Thysanoptera	868	36.52
Hemiptera	1,977	284.04
Coleoptera	1,324	2,434.63
Strepsiptera	0	4.46
Diptera	848	1,217.32
Siphonaptera	0	19.31
Lepidoptera	995	1,217.32
Hymenoptera	144	933.28
Zoraptera	0	0.24
Acari	539	243.46

Interceptions by Customs and Border Protection (CBP). Twelve orders of arthropods accounted for 98% of all interceptions made by CBP (Tables 2 & 3; Fig. 2). Hemiptera comprised 28% of the interceptions, Coleoptera comprised 19%, Lepidoptera 14%, and Thysanoptera and Diptera each comprised 12%. Four families accounted for 79% of all Hemiptera intercepted; Aphididae with 28%, Pseudococcidae with 27%, Diaspididae with 18% and Coccidae with 6%. Three families accounted for 59% of all Coleoptera intercepted; Curculionidae with 51%, Tenebrionidae with 4%, and Staphylinidae with 4%. One family, Noctuidae, accounted for 48% of all Lepidoptera intercepted.

Twelve taxa were intercepted more than 100 times by CBP and accounted for 43% of all interceptions (Table 3). The most commonly intercepted taxon was *Frankliniella* spp., including *F. occidentalis* and *F. panamensis*, accounting for 9% of interceptions. 86% of the intercepted *Frankliniella* originated in Colombia. The

Table 3. Taxa intercepted from foreign countries.

Species	Order	Family	Number intercepted
Frankliniella sp.	Thysanoptera	Thripidae	439
Sternochetus mangiferae	Coleopoptera	Curculionidae	415
Pseudococcidae sp.	Hemiptera	Pseudococcidae	345
Noctuidae sp.	Lepidoptera	Noctuidae	277
Agromyzidae sp.	Diptera	Agromyzidae	245
Lepidoptera sp.	Lepidoptera		240
Aphididae sp.	Hemiptera	Aphidae	195
Liriomyza huidobrensis	Diptera	Agromyzidae	176
Frankliniella occidentalis	Thysanoptera	Thripidae	132
Raoiella indica	Acari	Tenuipalpidae	132
Mesostigmata sp.	Acari	Phytoseidae	119
Parlatoria ziziphi	Hemiptera	Diaspididae	103
Copitarsia sp.	Lepidoptera	Noctuidae	87
Diaspididae sp.	Hemiptera	Diaspididae	86
Plutella xylostella	Lepidoptera	Plutellidae	82
Miridae sp.	Hemiptera	Miridae	80
Dysmicoccus brevipes	Hemiptera	Pseudococcidae	77
Thripidae sp.	Thysanoptera	Thripidae	73
Cucujidae sp.	Coleoptera	Cucujidae	71
Macrosiphum euphorbiae	Hemiptera	Aphidae	71
Tydeidae sp.	Acari	Tydeidae	69
Liriomyza trifolii	Diptera	Agromyizidae	64
Anthocoridae sp.	Hemiptera	Anthocoridae	63
Psocoptera sp.	Psocoptera		62
Aulacorthum solani	Hemiptera	Aphidae	61
Liriomyza sp.	Diptera	Agromyizidae	55
Tetranychus; Probably urtic.	Acari	Tetranychidae	55
Aulacaspis tubercularis	Hemiptera	Aphidae	52
Myzus persicae	Hemiptera	Aphidae	52
Syrphidae sp.	Diptera	Syrphidae	52
Thrips tabaci	Thysanoptera	Thripae	49

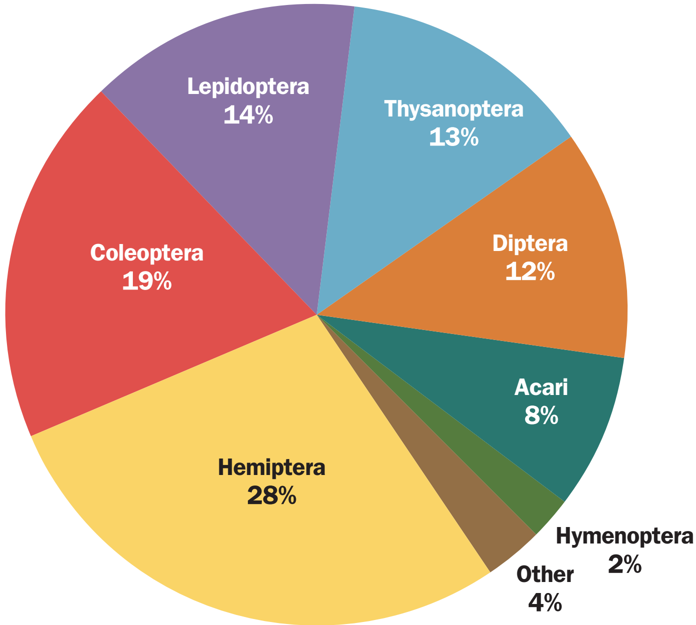

Fig. 2. Percentage of interceptions by Customs and Border Patrol, by Arthropod Order

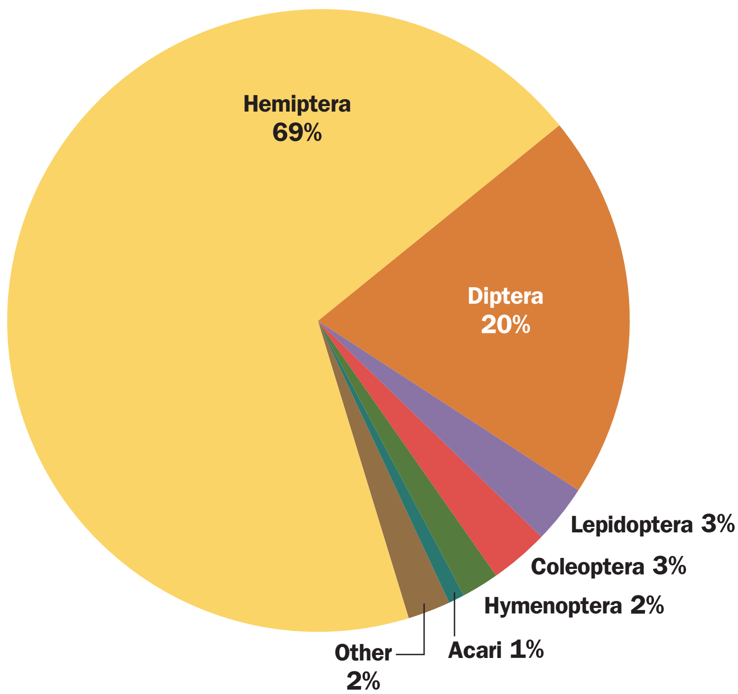

Fig. 3. Percentage of interceptions by APHIS-PPQ, by Arthropod Order

mango seed weevil, *Sternochetus mangiferae*, was the second most frequently intercepted taxon, accounting for 6% of interceptions. *Sternochetus mangiferae* was intercepted only in traffic originating in the Caribbean, with 64% of the interceptions of this beetle coming from St. Lucia, Dominica, Grenada, and St. Vincent.

Interceptions by APHIS-PPQ. Twelve orders of arthropods accounted for 99% of all interceptions made by APHIS-PPQ (Table 4; Fig. 3). Hemiptera comprised 69% of the interceptions, Diptera comprised 20%, Lepidoptera comprised 3%, Hymenoptera comprised 2%, Acari comprised 1%. The remaining orders (Psocoptera, Collembola, Thysanoptera, Orthoptera, Neuroptera, Isoptera, and Odonata) each comprised less than 1%. Three families accounted for 96% of all Hemiptera intercepted: Diaspididae with 65%, Pseudococcidae with 24%, and Coccidae with 7%. Two families accounted for 90% of all Diptera intercepted; Tephritidae with 58% and Agromyzidae with 32%. Two families (Noctuidae with 47% and Pyralidae with 31%) accounted for 78% of the Lepidoptera intercepted. Most (56%) of the Coleoptera intercepted were weevils (Curculionidae) and 93% of the Hymenoptera intercepted were ants (Formicidae).

Table 4. Frequency of actual interceptions by APHIS-PPQ on materials to be exported from Puerto Rico by order and the expected frequency based on the proportion of the Puerto Rican fauna that these make up. (Maldonaldo-Capriles 1996)

Order	Observed	Expected
Protura	0	5.83
Diplura	0	3.88
Thysanura	0	7.77
Collembola	42	132.05
Dermaptera	0	19.42
Orthoptera	17	211.68
Isoptera	2	34.96
Embioptera	0	1.94
Psocoptera	68	33.01
Phthiraptera	0	93.21
Ephemeroptera	0	38.84
Odonata	1	89.33
Neuroptera	6	46.61
Trichoptera	0	66.03
Thysanoptera	28	192.26
Hemiptera	6,738	1,778.85
Coleoptera	291	2,132.29
Strepsiptera	0	1.94
Diptera	1,907	1,749.72
Siphonaptera	0	13.59
Lepidoptera	297	2,029.37
Hymenoptera	225	1,155.48
Zoraptera	0	1.94

Species richness as a predictor of interceptions. We compared the frequency of interceptions within an order to the expected frequency within an order based on number of species in each order (Tables 2 & 4). To obtain the expected frequency of interceptions within a given order, we multiplied the total number of arthropods intercepted from foreign countries (6,952) or from Puerto Rico (9,840) by the proportion of species in a given order, using estimates of the number of world-wide species in that order based on Triplehorn and Johnson (2005) or the estimated number of species in that order in Puerto Rico (Maldonaldo Capriles 1996).

International Interceptions. Some orders were under-represented in interceptions, including Orthoptera (<1/3 of the expected number were intercepted), Neuroptera (<1/5 of the expected number were intercepted), Trichoptera (<1/28 of the expected number were intercepted), Coleoptera (≈1/2 of the expected number were intercepted), and Hymenoptera (<1/6 of the expected number were intercepted) (Table 2).

Mites (order Acari) were intercepted twice as frequently as would be expected based on the number of mite species in the world. Hemiptera, including scales, aphids, and other former Homoptera, were intercepted almost seven times more frequently than expected based on the number of species in these orders worldwide (Table 2). Thysanoptera were intercepted 24 times more frequently than expected based on the number of species in these orders worldwide (Table 2).

Domestic Interceptions. Orders under-represented in domestic interceptions included Collembola (≈1/3 the expected number), Orthoptera (≈1/12 the expected number), Isoptera (≈1/17 the expected number), Odonata (≈1/89 the expected number), Neuroptera (≈1/8 the expected number), Thysanoptera (≈1/7 the expected number), Coleoptera (≈1/7 the expected number), Lepidoptera (≈1/7 the expected number), and Hymenoptera (≈1/5 the expected number) (Table 4).

Psocoptera were intercepted twice as often than would be expected based on the number of species reported from Puerto Rico, and Hemiptera were intercepted almost four times more frequently than would be expected (Table 4).

Propagule pressure as a predictor of interceptions. Of 28 adventive arthropods recently established in Puerto Rico, only seven were intercepted during this study (Table 5). However, the most frequently intercepted species from foreign countries included adventives that have been established in Puerto Rico (e.g., *Frankliniella* spp., *Raoiella indica* and *Parlatoria ziziphi*) (Table 3). *Sternochetus mangiferae* was the second most common insect intercepted and all interceptions were from 19 Caribbean countries. For many of these countries, *S. mangiferae* made up a relatively large portion of the interceptions, averaging 33% of interceptions per country.

Mainland U.S. as a source of adventive arthropods. No interceptions were recorded from mainland U.S. because no agency is inspecting traffic entering Puerto Rico and the Virgin Islands from the mainland U.S. Because we have no data concerning the arthropods coming from the mainland U.S. to Puerto Rico and the Virgin Islands, we decided to analyze adventive arthropods that have established in both Florida and Puerto Rico and compare the year they were first reported in each location. We chose Florida because of its proximity to the Caribbean, similar climate and host plants, and the volume of travel between Puerto Rico and Florida.

Of 17 species that have established in Puerto Rico and Florida in the last 30 years, only two were reported in Puerto Rico before they were reported in Florida, and two were reported the same year in both Florida and Puerto Rico (Table 7). Both of the organisms that were reported in Puerto Rico before being reported in Florida were well established in other parts of the Caribbean prior to being reported in Florida.

Conclusions

Protecting national agriculture and ecosystems from invasive adventives is extremely important. The task is difficult due to the large volume of traffic and the global reach of that traffic. Being able to focus on specific pests or specific regions can greatly improve the efficiency of detection and enacting control measures in a timely manner. However, predicting potential pests and likely origins for these pests is almost impossible. Interceptions made by regulatory agencies provide a snapshot in time of patterns that may be useful in predicting future pests and their routes of arrival.

Most interceptions from foreign countries were on traffic originating in Caribbean countries and are probably due to the frequency of traffic and trade between Puerto Rico and these countries. Because Puerto Rico imports much of its food, most

Table 5. Taxa intercepted from Puerto Rico.

Species	Order	Family	Number intercepted
Aulacaspis tubercularis	Hemiptera	Diaspididae	2,130
Parlatoria ziziphi	Hemiptera	Diaspididae	1,645
Pseudococcidae sp.	Hemiptera	Pseudococcidae	1,265
Anastrepha sp.	Diptera	Tephritidae	1,071
Melanagromyza sp.	Diptera	Agromyzidae	477
Diaspididae sp.	Hemiptera	Diaspididae	246
Melanagromyza obtusa	Diptera	Agromyzidae	113
Coccus viridis	Hemiptera	Coccidae	106
Helicoverpa zea	Lepidoptera	Noctuidae	92
Coccidae sp.	Hemiptera	Coccidae	88
Planococcus citri	Hemiptera	Pseudococcidae	80
Dysmicoccus brevipes	Hemiptera	Pseudococcidae	79
Sternochetus mangiferae	Coleoptera	Curculionidae	78
Vinsonia stellifera	Hemiptera	Coccidae	76
Raoiella indica	Acari	Tenuipalpidae	73
Wasmannia auropunctata	Hymenoptera	Formicidae	73
Selanaspidus articulatus	Hemiptera	Diaspididae	70
Psocoptera sp.	Psocoptera		67
Diaphania nitidalis	Lepidoptera	Pyralidae	66
Ceroplastes rubens	Hemiptera	Coccidae	58
Lepidosaphes beckii	Hemiptera	Diaspididae	58
Drosophilidae sp.	Diptera	Drosophilidae	54
Planococcus minor	Hemiptera	Pseudococcidae	52
Aonidiella orientalis	Hemiptera	Diaspididae	51
Aleyrodidae sp.	Hemiptera	Aleyrodidae	50

interceptions were made on commercial shipments of fruits and vegetables. In addition, many of the interceptions were made on cut flowers from Colombia and on Christmas trees from Canada.

The arthropod orders intercepted generally reflected the species richness of those orders, except that Hemiptera was the most intercepted order. Regulatory agencies could further focus their efforts on pests, particularly hemipterans (scale insects, mealybugs, etc.) and thrips, which would affect current and foreseeable agriculture commodities, including bananas, plantains, coffee, mangoes, and citrus.

There were differences in the frequency of taxa intercepted from foreign countries and from Puerto Rico. These differences likely represent the much more finite population of potential arthropods on the island of Puerto Rico than the population of potential arthropods in the whole Caribbean and the rest of the world. They are also affected by the nature of the traffic. Most of the interceptions from foreign countries were on cut flowers and fruits and vegetables for commercial sale. Most of the interceptions from Puerto Rico were on fruits, such as mango, carried by passengers traveling to visit family in the U.S. This explains the large number of interceptions of fruit flies in the genus *Anastrepha*, and the interception of scales and mealybugs, which are likely to be present on fruit.

Lastly, most invasive arthropods that were established in Puerto Rico and Florida were reported from Florida first. It is possible that Florida has more "eyes on the problem" than Puerto Rico and discovery is likely to be more rapid there. It is also possible that the lack of inspection for traffic coming into Puerto Rico from the mainland U.S. is a weak link in the defense of Puerto Rican agriculture. In 1994, an estimated 85% of all plants of foreign origin imported into the U.S. entered through Miami International Airport (Frank and McCoy 1995). Furthermore, there are important pests in Florida that would have a devastating effect on Puerto Rican agriculture and ecosystems if they established there, including the redbay ambrosia beetle, which vectors the fungus responsible for laurel wilt, and *Metamasius callizona* (Chevrolat) (Coleoptera: Dryophthoridae), an invasive beetle that is wreaking havoc on Florida's bromeliad populations (Frank and Fish 2008; Cooper et al. 2013) and could do the same to Puerto Rico's bromeliad flora and pineapple industry. There are obviously tradeoffs implementing inspections on incoming traffic, including increased costs and the potential to discourage visitors, but it is noteworthy that Hawaii has had a system to inspect incoming traffic for years.

Table 6. Exotic arthropods established in Puerto Rico and the number of times they were intercepted during this study.

Species	Order	Family	Number of times intercepted
Cactoblastis cactorum	Lepidoptera	Pyralidae	0
Aceria guerreronis	Acari	Eriophyidae	0
Solenopsis invicta	Hymenoptera	Formicidae	6
Psuedacysta perseae	Hemiptera	Tingidae	0
Paracoccus marginatus	Hemiptera	Pseudococcidae	3
Maconellicoccus hirsutus	Hemiptera	Pseudococcidae	12
Hypogeococcus pungens	Hemiptera	Pseudococcidae	0
Technomyrmex difficilis	Hymenoptera	Formicidae	0
Raoeiella indica	Acari	Tenuipalpidae	132
Zaprionus indianus	Diptera	Drosophilidae	0
Papilio demoleus	Lepidoptera	Papilionidae	0
Holopothrips tabebuiae	Thysanoptera	Phlaeothripidae	0
Crypticerya genistae	Hemiptera	Margarodidae	1
Scirtothrips dorsalis	Thysanoptera	Thripidae	0
Hypothenemus hampei	Coleoptera	Curculionidae	0
Planococcus minor	Hemiptera	Pseudococcidae	54
Aulacaspis yasumatsui	Hemiptera	Diaspididae	0
Diaphorina citri	Hemiptera	Psyllidae	0
Bedellia somnulentella	Lepidoptera	Bedelliidae	4
Diabrotica balteata	Coleoptera	Chrysomelidae	0
Alecanochiton marquesi	Hemiptera	Coccidae	0
Oxycarenus hyalinipennis	Hemiptera	Oxycarenidae	0
Singhiella simplex	Hemiptera	Aleyrodidae	0
Phalacrococcus howertoni	Hemiptera	Coccidae	0
Toumeyella parvicornis	Hemiptera	Coccidae	0
Paratachardina pseudolobata	Hemiptera	Kerridae	0
Michaelophorus nubilus	Lepidoptera	Pterophoridae	0
Quadrastichus erythrinae	Hymenoptera	Eulophidae	0

Case Studies of Adventive Arthropods Established in Puerto Rico

***Hypogeococcus pungens* Granara de Willink (Hemiptera: Pseudococcidae): the Harrisia cactus mealybug.** The Harrisia cactus mealybug is one of the premier biological control organisms on earth (McFadyen and Tomley 1981; Moran and Zimmerman 1991). Cacti are not native to the Old World, and in some regions, including Australia and South Africa, cacti have become noxious weeds. The mealybug was imported from its native Argentina to Australia and South Africa to manage columnar cactus species, and it was successful in reducing cacti to manageable populations. However, its arrival in Puerto Rico was met with alarm, since there are native and endangered cacti present on the island (Liogier 1994). These cacti are integral components of Puerto Rico's dry forests and their removal has a serious impact on dry forest equilibrium. The mealybug also poses a considerable threat to columnar cacti in the desert southwest of North America and Mexico, where there is an abundance of native cacti that are ecologically and economically important. Although *H. pungens* has been reported from Barbados and Florida (Hamon 1984; Hodges and Hodges 2009), neither of those locations reported significant damage to cacti. In Puerto Rico, however, whole forests of cactus were infested with galls, and research plots in Guánica Forest have lost >80% of their columnar cacti individuals since 1999 (Van Bloem, unpublished data). This suggests the existence of host biotypes or even confusion at the species level. To date, this problem has not been satisfactorily resolved.

APHIS did intercept *H. pungens* once in 2000, but it has not been intercepted at any other time, including during this study (Table 6). Only the adult males of *H. pungens* can fly, but since they do not carry females and are not able to start colonies themselves, they are not responsible for dispersing populations. Dispersal of populations can occur in two ways: transport of plant material containing mealybugs (adults and juveniles) and active

Table 7. Exotic arthropod species found in Puerto Rico and Florida, with the years they were first reported in each location.

Species	Year Reported in PR	Year Reported in FL	References
Pseudacysta perseae	1991	1908	Heidemann 1908, Medina-Gaud et al. 1991.
Solenopsis invicta	1982	1970	Buren 1982
Maconellicoccus hirsutus	1999	2002	Hoy et al. 2006
Aulacaspis yasumatsui Takagi	1999	1999	Howard et al. 1999; Segarra-Carmona & Pérez-Padilla 2008
Technomyrmex difficilis	2000	1990	Deyrup 1991; Wetterer 2008
Diaphorina citri	2001	1998	Halbert et al. 1998; Halbert & Nuñez 2004
Hypogeococcus pungens	2005	1984	Hamon 1984; Segarra-Carmona et al. 2010
Zaprionus indianus	2007	2005	Steck 2005
Holopothrips tabebuiae	2007	2001	Cabrera & Segarra 2008
Crypticerya genistae	2007	2005	Hodges 2008
Scirtothrips dorsalis	2008	2005	Hodges et al. 2005; Klassen et al. 2008
Planococcus minor	2008	2010	Stocks & Roda 2011
Singhiella simplex	2008	2007	Hodges 2007; Mannion et al. 2008
Phalacrococcus howertoni	2010	2008	Hodges & Hodgson 2010
Paratachardina pseudolobata	2010	1999	Hamon 2001; Segarra-Carmona & Cabrera-Asencio 2010
Quadrastichus erythrinae	2012	2006	Wiley & Skelley 2006
Xyleborus glabratus	?	2005	Hanula et al. 2008

dispersal by crawlers, the mobile juvenile stage of the mealybug. Crawlers can crawl to a new host, or they may be carried by wind or animals, particularly birds. Although the mealybug has been established on the main island of Puerto Rico since before 2005, populations have not been recorded on the islands of Caja de Muerto (approximately 6 km south of the island of Puerto Rico), Mona (66 km west of the island of Puerto Rico), or Desecheo (21 km west of the island of Puerto Rico). This suggests that water poses a significant barrier to the dispersal of the insect.

***Technomyrmex difficilis* Forel (Hymenoptera: Formicidae).** Ants (Hymenoptera: Formicidae) make up a large proportion of invasive species. A compilation of the worst invasive aliens (admittedly subjective in nature) included 17 invertebrates, of which five were ant species (Lowe et al. 2000). *Technomyrmex difficilis* did not make this rogues' gallery, but it shares many of the traits that are characteristic of other invasive ants, including open societies that are not aggressive towards other members within the same species; a vague delineation between a colony and a population, with many individuals moving from one nest to another; polygynous colonies (multiple reproductive females in each colony); and colony reproduction by fission or budding (Passera 1994). *Technomyrmex dificilis* can be extremely common in areas of Puerto Rico and occupies a very similar niche to that of the crazy ant, *Paratrechina longicornus*. Nests can range from five individuals with brood in a rolled-up leaf (although many rolled-up leaves on a tree add up to make a pretty large colony) to thousands of individuals in unused termite domiciles, sheaths of banana pseudostems, or any other shelter they can find (DAJ personal observations; Deyrup 1991). Though they can form a considerable part of the biomass in orchards and forests, they are rare home invaders and so do not attract the attention of humans. Nonetheless, their sheer numbers and their propensity to tend honeydew-producing Hemipterans suggest that they can have an impact on agriculture. This ant was not intercepted during the study.

***Raoiella indica* Hirst (Acari: Tenuipalpidae): the red palm mite.** The red palm mite is notable for being intercepted more frequently during this study than any of the other adventive arthropods recently established in Puerto Rico (Table 6). It was also from Puerto Rico within a year of being reported in Florida (Rodriguez et al. 2007; Welbourn 2009). Feeding through the stomata of palms and bananas, the red palm mite reduces the photosynthetic efficiency of these plants. It is rare to see coconut palms whose fronds are a rich green instead of the reddish brown indicative of high populations of the mites. It is not clear if coconuts and other palms are declining on the island or even if the red palm mite is contributing to that decline. To date, the banana industry has not changed any of their management practices in response to the mite.

***Maconellicoccus hirsutus* (Green) (Hemiptera: Pseudococcidae): the pink hibiscus mealybug.** The pink hibiscus mealybug is one of only two arthropods reported from Puerto Rico before it was reported in Florida. Regulatory and extension personnel were aware of the threat of the pink hibiscus mealybug (it has a broad host range, including some economically important crops and ornamentals) and its migration through the Caribbean to Florida was anxiously monitored (Williams 1996). A very successful biological control program was set up, including survey methods and rearing and releasing natural enemies (Meyerdirk et al. 2002). The mealybug remains in Puerto Rico, but its damage is largely suppressed by natural enemies. It was intercepted 12 times during this study (Table 6).

***Zaprionus indianus* Gupta (Diptera: Drosophilidae).** The broad host range of this vinegar fly was worrisome to fruit growers, but it usually is restricted to fruit that is already damaged. This fly is abundant on rotten fruit in Puerto Rico, but growers have not changed management practices in response to its arrival, indicating that its economic impact is negligible. This fly was never intercepted during the study (Table 6).

***Holopothrips tabebuiae* Cabrera & Segarra (Thysanoptera: Phlaeothripidae).** Thrips (Thysanoptera) make up a large portion of the world's invasive fauna, and they can have an enormous economic impact. Thrips were the third most intercepted order of arthropods in this study (Table 2). However, this species was not intercepted during the study (Table 6). The origin of this thrips species is unclear (Cabrera and Segarra 2008), but the damage to species of *Tabebuia*, especially *T. heterophylla* (Bignoniaceae), is so apparent that its arrival in Florida and in Puerto Rico was immediately noted by laypeople and scientists alike. Despite infestations throughout the island of Puerto Rico, *Tabebuia* trees appear to be thriving. Seedling recruitment remains high (DAJ personal observation) and the deformed leaves characteristic of this thrips have become a part of the phenotype of *T. heterophylla* throughout the island.

***Crypticerya genistae* (Hempel) (Hemiptera: Margarodidae).** There was some concern when this insect was first reported in Puerto Rico because it can be a devastating pest of soybeans and other legumes. It has become widespread on the island, usually on pigeon pea (*Cajanus cajan*: Fabaceae) and on wild Malvaceae. It is often attacked by larvae and adults of the lady beetle *Rodolia cardinalis* (Coleoptera: Coccinellidae) and, though common, populations remain low. Only one individual was intercepted during this study (Table 6).

***Planococcus minor* (Maskell) (Hemiptera: Pseudococcidae): passionvine mealybug.** The broad host range of this mealybug worried regulatory agencies, and some pro-active efforts were made to prepare for the arrival of this mealybug onto mainland U.S. (Venette and Davis 2004). Although widespread on the island, this mealybug does not appear to be having an economic or ecological impact. After the red palm mite, this was the most frequently intercepted arthropod of the adventive arthropods that were already established in Puerto Rico.

***Pseudacysta perseae* (Heidemann)(Hemiptera: Tingidae): avocado lace bug.** The avocado lace bug garnered a lot of attention when it first arrived in Puerto Rico, but *Phytophthora* root rot (*Phytophthora cinnamomi*) has had a deeper impact on the management practices of avocado growers. The lace bug is widespread on the island and so common that the foliar damage has become a part of avocado's phenotype in Puerto Rico. This insect was not intercepted during the study.

***Diaphorina citri* Kuayama (Hemiptera: Liviidae): Asian citrus psyllid.** This arthropod has probably had the greatest impact on Puerto Rican agriculture in recent memory. The psyllid itself does little damage to citrus trees. However, it vectors the causative organism of citrus greening disease, or huanglongbing. There is no cure for infected trees and production immediately declines. There is no doubt that citrus production is in steep decline on the island and it is possible that citrus production will cease to exist on Puerto Rico. Both the insect and the disease were first reported in Florida and some investigative efforts were conducted early in Puerto Rico, but the disease and its vector were largely ignored. Even in Florida, where very proactive efforts were made to anticipate the psyllid and the disease, citrus is a threatened industry.

***Paratachardina pseudolobata* (Kondo and Gullan) (Hemiptera: Kerriidae): the lobate lac scale.** This enigmatic scale was first reported in Florida and efforts were made to investigate biological control methods. These efforts were unsuccessful and the scale has spread. It has an enormous host range and where populations are high, there is serious dieback. Nonetheless, large populations of this scale appear to be restricted to sick trees or greenhouse conditions. No biological control agents have been reported for this insect and it is unclear what is regulating populations.

***Quadrastichus erythrinae* Kim (Hymenoptera: Eulophidae): the erythrina gall wasp.** This tiny wasp (approx. 1 mm in length) oviposits in species of *Erythrina*, causing deformation of the foliage. The arrival of this wasp in Puerto Rico is somewhat baffling. It was first reported in Hawaii and then Florida, and finally in Puerto Rico. The large distances between these regions support human transport of the erythrina gall wasp. Its only hosts are *Erythrina* species, so it would have to come in on infested *Erythrina* plants. Many *Erythrina* species are valued as ornamentals, so it is plausible that the wasp was brought in on imported plants. However, the wasp and its damage were known to occur in Hawaii and Florida, so it is surprising that some quarantine and intensive inspection was not imposed in imports of *Erythrina* species. Unless this was a deliberate act of sabotage, this would seem to be an avoidable introduction. Of seven species of *Erythrina* found in Puerto Rico, the most affected by the wasp appears to be the adventive *E. variegata*. Many *Erythrina* species are common roadside trees that easily sprout from cuttings. It is likely the effect of this wasp will be small in Puerto Rico.

***Hypothenemus hampei* (Ferrari) (Coleoptera: Curculionidae): the coffee berry borer.** This tiny scolytid beetle had been on Puerto Rico's radar for years. Native to Africa, the coffee berry borer moved to Brazil in the 1920s, was found in Central America in the 1970s, and was reported in Colombia in the late 1980s (Guadalupe Rojas et al. 1999). It had been in the Dominican Republic since the 1990s (Schmutterer 1990), and so Puerto Rico was well aware of the threat it posed. Surveys were regularly conducted in Puerto Rico (Vega et al. 2002), and finally it was discovered there in 2007. This insect has had an effect on the already declining coffee cultivation by reducing the productivity of coffee farms; up to 50% of harvested coffee berries were infested and not useable. Coffee, the only host of this beetle, is not cultivated in Florida, so this pest is limited to Puerto Rico and Hawaii in the U.S.

Predicting the Arrival of Adventive and Invasive Arthropods

Some adventive arthropods that have established in Puerto Rico were predicted, in some cases many years before establishing in Puerto Rico. The coffee berry borer had been causing damage to coffee for decades in South America (Vega et al. 2009). Since coffee has been an important commodity in Puerto Rico, the arrival of this devastating pest was anticipated (Vega et al. 2002) and steps were taken to monitor for it and restrict imports of potentially infested coffee. Similarly, *Diaphorina citri* had been known as a vector of citrus greening disease and had been reported in the western hemisphere decades before it arrived in Puerto Rico and Florida. Despite these steps, both of these pest arthropods have arrived in Florida and Puerto Rico.

Other invasive species should have been predicted. The erythrina gall wasp had been causing serious damage to *Erythrina* species in Hawaii before it was detected in Florida and Puerto Rico. Furthermore, its limited host range (only trees in the genus *Erythrina*) should have facilitated quarantining this pest by restricting imports of these trees. Of the arthropods anticipated to establish in Puerto Rico or Florida, only the pink hibiscus mealybug has been successfully suppressed thanks to action taken early.

The arrival and establishment of most invasive arthropods has not been anticipated, and in many cases, anticipation of particular invasions would be impossible. For instance, the redbay ambrosia beetle, which has not yet been reported in Puerto Rico, does not attack living trees in its native Asia, but the populations that established in the southeastern United States attack living trees in the Lauraceae, transmitting a fungus that is lethal to the trees (Fraedrich et al. 2008). There was no way of reliably predicting that this beetle would become a substantial threat if it successfully established in the United States. However, the redbay ambrosia beetle is a pest in Florida and the most likely mode of transport would be wood, including shipping pallets, which have been implicated in numerous arthropod pest invasions. Predicting which species may invade via pallets may be difficult, but predicting that species will invade via pallets is a certainty. The arrival of the redbay ambrosia beetle and its associated fungus that causes laurel wilt would devastate the Caribbean avocado industry. Attractant chemicals have been identified (Hanula and Sullivan 2008) and effective traps have been designed (Kendra et al. 2011). These traps can be deployed in ports of entry and inspection officers can be made aware of the dangers wood products pose.

Other invasives, including *Technomyrmex difficilis*, *Planococcus minor*, *Crypticerya genistae*, and *Pseudacysta perseae*, have established in Puerto Rico, but their impact has been (until now) minor. They may remain innocuous or they may have increased impact in the future.

In summary, predicting invasives is extremely difficult. Random events, such as founder effects, can drastically change a benign organism into a devastating pest, as happened with the redbay ambrosia beetle. Preventing the arrival of anticipated pests has proven difficult in the past, e.g., the arrival of the coffee berry borer and the Asian citrus psyllid. Nonetheless, regulatory agencies intending to protect Puerto Rican agriculture and environment can work more efficiently by identifying pests occurring in the Caribbean and Florida, determining the most likely manner of transport of these pests, developing monitoring and detection methods for these pests, and educating officers on these pests. These are actions that APHIS and CBP already conduct frequently. However, the lack of inspection of materials coming into Puerto Rico from the U.S. mainland is a major weakness in the protection of the island's agricultural industry.

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David A. Jenkins, USDA-ARS Tropical Agriculture Research Station, Mayaguez, PR. **Russell F. Mizell**, III, University of Florida, North Florida Research and Education Center, Quincy, FL. **Skip Van Bloem**, Clemson University Belle W. Baruch Institute of Coastal Ecology and Forest Science, Georgetown, SC. **Stefanie Whitmire**, Shaw University Department of Natural Science and Mathematics, Raleigh, NC. **Leyinska Wiscovitch**, USDA-APHIS, San Juan, PR. **Crystal Zaleski**, USDA-APHIS, San Juan, PR. **Ricardo Goenaga**, USDA-ARS Tropical Agriculture Research Station, Mayaguez, PR.

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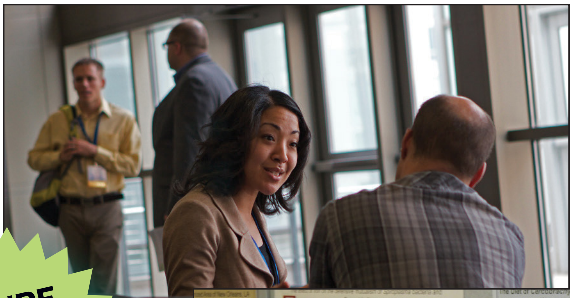

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