FORUM

High Levels of Exotic Armored Scales on Imported Avocados Raise Concerns Regarding USDA–APHIS' Phytosanitary Risk Assessment

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ABSTRACT Between 1914 and 2007, a quarantine protected California avocado, *Persea americana* Mill., groves from pests that might be introduced into the state along with fresh, imported avocados. Soon after Mexican avocados were first allowed entry on 1 February 2007, live specimens of several species of armored scales (Hemiptera: Diaspididae) not believed to be present in California were detected on 'Hass' avocados entering the state from Mexico. Initially, the California Department of Food and Agriculture (CDFA) prevented avocados infested with these scales from entering the state or required that they be fumigated with an approved treatment such as methyl bromide. After a Science Advisory Panel meeting in May 2007, U.S. Department of Agriculture–Animal and Plant Health Inspection Service (USDA–APHIS) reaffirmed its position that armored scales on shipments of fruit for consumption (including avocados) pose a "low risk" for pest establishment. In compliance with APHIS protocols, as of 18 July 2007, CDFA altered its policy to allow shipments of scale-infested avocados into the state without treatment. Here, we report on sampling Mexican avocados over an 8-mo period, September 2007–April 2008. An estimated 67 million Mexican Hass avocados entered California over this period. Based on samples from 140 trucks containing ≈15.6% of this volume of fruit, we estimate that ≈47.6 million live, sessile armored scales and an additional 20.1 million live eggs and crawlers were imported. We found eight probable species of armored scales in the samples, seven of these are not believed to occur in California; 89.3% of the live scales were *Abgrallaspis aguacatae* Evans, Watson and Miller, a recently described species. In contrast to the USDA–APHIS opinion, we believe the volume of shipments and levels of live scales they contain present a significant risk to California's US$300 million avocado industry and to other crops that might become infested by one or more of these exotic species.

KEY WORDS Diaspididae, *Abgrallaspis aguacatae*, risk assessment, crawlers, invasive pests

Commercial production of avocado, *Persea americana* Mill., in the United States began in Florida ≈1900 (Webber 1916). The first commercial avocado grove in California was planted in Los Angeles County in 1908 (Shepherd and Bender 2002), and by 1916 there were 121–162 ha of trees in the state (Webber 1916). To safeguard fledgling industries in both states, as of 27 February 1914, the U.S. Department of Agriculture (USDA) imposed a quarantine on shipment of seed-containing avocados (i.e., fresh fruit) into the United States from Mexico and Central America because of the presence of avocado seed weevil, *Heilipus lauri* Boheman, in those regions (Bellamore 2003). In 1973, the list of pests justifying the quarantine was expanded to include avocado seed moth, *Stenoma catenifer* Walsingham, and several weevils in the genus *Conotrachelus.* Passage of the North American Free Trade Agreement (NAFTA) in 1994 and creation of the World Trade Organization in 1995 were two of several factors leading to increased interest in facilitating trade between the United States and Mexico. USDA's Animal and Plant Health Inspection Service (APHIS) is the primary U.S. agency charged with overseeing importation of fruits and vegetables into the country and with the phytosanitary provisions of NAFTA and other trade agreements (Bellamore 2003). In 1995, APHIS published a Proposed Rule (King 1995) that eventually led to importation of fresh Mexican 'Hass' avocados into parts of the United States. Two pest risk analyses were used to justify this rule (APHIS 1995, Miller et al. 1995). As of 25 February 1997, Mexican avocados were permitted entry into 19 northeastern states of the United States between November and February each year, partly because pest establishment was considered less likely in those states during the winter. In 2001, the number of states permitted to import Hass avocados from Mexico was expanded to 31, and the shipping season was extended from 15 October to 15 April. As of 1 February 2007, all 50 U.S.

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states were opened to shipment of Mexican avocados year-round.

The California Department of Food and Agriculture (CDFA) has jurisdiction over shipments of agricultural products entering California through borders with other U.S. states. There are 16 CDFA agricultural border inspection stations, including one at Blythe, CA, that to date has received the largest volume of Mexican avocados. When Mexican Hass avocados began entering California, CDFA inspectors detected several species of armored scale (Hemiptera: Diaspididae) on the fruit skins (G.W.W., unpublished data). Trucks found to contain live armored scales not known to be present in California were required to be treated with an approved material such as methyl bromide or were denied entry into the state. CDFA maintained this policy until 18 July 2007.

The U.S. Department of Homeland Security (DHS), in collaboration with USDA–APHIS Plant Protection and Quarantine (PPQ), conducts inspections and has jurisdiction over U.S. entry points bordering Mexico and Canada and at ports receiving international shipments. On 4 October 2000, USDA–PPQ made a policy change in which ". . . avocado fruit for consumption has been added to the list of commodities which do not require action when armored scales are intercepted on commercial shipments" (APHIS 2006). This policy had previously applied to armored scales found on stone fruit (i.e., the hard-seeded drupes of *Prunus* spp., almonds, apricots, cherries, nectarines, peaches, plums, and prunes), pome fruit (apples, pears, hawthorn, quince, and other related Rosaceae), kiwifruit, citrus, and banana. The policy originally went into effect 8 September 1986 and was based on an unpublished 1985 ad hoc report by a working group of four scientists (see the Miller 1985 reference cited in APHIS 2007a). Avocados were added to the above list of fruit in 2000, and as of 25 March 2008, the policy was expanded to include "all consumption commodities," i.e., all commercial shipments of produce for consumption.

Due in part to the untenable conflict between CDFA and DHS policies on avocados and other fruits infested with armored scales, CDFA requested that USDA conduct a review of the pest risk assessment associated with armored scales entering California on imported fruit. A Science Panel was convened by USDA–APHIS in May 2007. In the case of imported Hass avocados from Mexico, it found there was inadequate information on the level of infestation and species composition of armored scales entering California (APHIS 2007b, Griffin et al. 2007). The levels of live eggs or crawlers (or of adult or nearly mature scales capable of producing eggs or crawlers) was considered critical to the potential risk of establishment because new armored scale populations can establish only via the crawler stage, which must find a suitable host and feeding site within ≈24 h of hatching (Greathead 1990).

Subsequent to this review, which assumed that fruit for consumption followed a pathway of progressive dispersion from import to the consumer, USDA–APHIS reaffirmed its policy that armored scale insects on commercial fruit for consumption entering the United States pose a "low risk" of pest establishment. In compliance with this policy, on 18 July 2007, CDFA issued a Pest Exclusion Advisory notifying inspectors that they should no longer reject commercial shipments of produce for consumption because of the presence of armored scales. As a result, Mexican avocados infested with exotic scales entering California via CDFA border inspection stations were allowed entry into the state without treatment.

The following study, funded by the California Avocado Commission, was designed to supply data for a more informed avocado armored scale pest risk assessment. We surveyed the armored scales present in shipments of Mexican Hass avocados entering California through the CDFA inspection station at Blythe, over an 8-mo period (from fall 2007 to spring 2008).

Materials and Methods

Source of Sampled Avocados. CDFA records indicated that among their inspection stations, the Blythe station received the highest transit volume of Mexican Hass avocados. With the assistance of CDFA inspectors at Blythe, we sampled levels of armored scales on commercial shipments of avocados entering California from Mexico 11 times (Table 1 provides volumes and dates). We destructively sampled one carton of fruit (mostly 11.3 kg) from each truck, for a total 140 trucks. The inspectors indicated that peak numbers of trucks were seen on Thursdays and Sundays, allowing shipments to arrive at markets on Fridays and Mondays. To maximize data capture, each 4.5-d sampling period started at Wednesday midnight and ended the following Monday between 10:30 a.m. and noon.

Following USDA–APHIS protocol, CDFA inspectors routinely cut sampled avocados into halves looking for the presence of internal pests such as larval fruit flies, weevils, or moths. We sampled cut fruit that were normally discarded after this inspection. The cut fruit were returned to the shipping carton and were held at the inspection station for collection on the last day of each sampling period. During the first two of the 11 sampling periods (Table 1), the fruit were held in a nonair-conditioned storage building at the inspection station before transport to the University of California (UC), Riverside. For subsequent sampling periods, the cartons were stored in a portable cold storage unit (model H68T, 1.8 by 2.4 m, Polar Leasing Company, Inc., Fort Wayne, IN) kept at 4.4°C. Based on Bills of Lading, this temperature was similar to truck transport temperatures, which varied between 4.4 and 6.7°C. Each carton was shipped with an exterior label indicating the fruit size, packinghouse identification number, and a grove identification code, which included the Mexican municipality from which the fruit were harvested. Bills of Lading listed when the fruit entered California and the number of cartons of each size of avocado on the truck. From these data, the total number of fruit on each truck was determined by summing the product of the number of cartons of each size and

Table 1. Volume of Mexican Hass avocados on trucks entering California via the Blythe border station September 2007–April 2008, which were subsampled over eleven 4.5-d sampling periods for the presence of armored scale insects

Blythe sample period	No. trucks	Total no. fruit examined per sample period (range/truck)	Total no. 11.3-kg cartons on trucks (range/truck)	Total no. fruit on trucks per sample period (range/truck)
20–24 Sept.	5	221 (36–57)	7,355 (960–1,600)	327,480 (25,400–96,000)
4–8 Oct.	12	580 (36–63)	14,506 (480–1,672)	861,038 (23,040–117,040)
18–22 Oct.	11	580 (39–67)	14,988 (616–1,679)	856,426 (36,960–96,000)
1–5 Nov.	20	1,054 (27–73)	30,548 (880–1,672)	1,686,536 (52,800–117,040)
15–19 Nov.	26	1,395 (24–86)	35,212 (280–1,680)	1,980,786 (16,800–140,448)
6–10 Dec.	18	902 (31–68)	25,411 (672–1,680)	1,275,668 (33,792–107,840)
3–7 Jan.	10	594 (45–91)	13,598 (550–1,680)	779,612 (32,640–117,040)
24–28 Jan.	10	513 (36–70)	13,984 (480–1,672)	712,352 (23,040–100,320)
14–18 Feb.	11	608 (31–92)	13,898 (763–1,672)	864,434 (34,480–117,040)
13–17 March	9	477 (39–85)	9,011 (80–1,600)	516,244 (4,800–141,504)
10–14 April	8	419 (36–90)	10,814 (720–1,672)	555,888 (25,280–140,448)
Mean ± SD, 11 sample periods	12.7 ± 6.1	667.5 ± 328.5	17,211.4 ± 9,061.8	946,951.3 ± 505,120.1
Total, all 11 sample periods	140	7,343	189,325	10,416,464

the number of fruit per carton (i.e., cartons with size 32 fruit have ≈32 fruit per 11.3-kg carton).

Fruit Sampling Protocol. Cartons of cut fruit were transported to UC Riverside, processed, and disposed of according to protocols outlined in CDFA permit no. 2513. Before transport, each carton was sealed at Blythe in a black garbage bag using duct tape. Samples were transported in a non-air-conditioned, camper-shell-covered truck bed to UC Riverside (≈3 h in transit) where they were stored at 5.6°C. The following morning, fruit to be inspected were placed at room temperature for 1–4 h to warm. After inspection, all fruit were again boxed, sealed, and placed at 79°C for 2.5 d to kill all living insects. After treatment, the sealed bags were disposed of in a covered landfill.

Each piece of cut fruit was inspected by a "primary inspector" under a dissecting microscope (8× to 35× magnification), and pieces of fruit bearing armored scales were placed in a secondary container. Infested pieces of fruit were then examined by one of four "secondary inspectors" (using 10× to 80× magnification), who determined the number, life stage, and viability (dead or alive) of each scale, and the likely species identity (based on digital pictures and feedback from molecular identifications). Secondary inspectors coordinated their inspections so they were consistent between inspectors, over time, and with respect to the appropriate species and life stage of scale being recorded. The cover of each scale was lifted using a small probe; viability was based on the scale body being shriveled and dry whereas live scales were turgid and actively exuded body fluids when pierced (after Walker et al. 1996). During each sampling period, a subsample of live, adult scales of each taxon was placed in 95% ethanol individually and stored at 4°C for subsequent molecular characterization. In addition, any parasitoid emergence holes found were recorded, and any larval, pupal, or adult parasitoids preserved individually for subsequent molecular identification (outside the scope of this article).

Estimation of Total Scale Numbers Entering California. To relate data from the 140 sampled trucks to the total numbers of Mexican Hass avocados entering California over our sampling period, records were obtained from the 13 California Avocado Marketing Research Information Center (AMRIC, California Avocado Commission, Irvine, CA) handlers importing Mexican avocados between 1 September 2007 and 30 April 2008. Table 2 lists the total volume of fruit imported over this period classified by fruit size and shows that ≈67.0 million fruit entered the state during this 8-mo period. There were two likely sources of error in these data: 1) Some portion of this fruit may have been transported into California before being shipped onwards to final destinations outside the state and 2) other fruit were imported into California by entities other than the 13 AMRIC handlers. Given the number of non-AMRIC handlers of Mexican avocados entering California, we believe the 67.0 million fruit estimate is an underestimate. Table 3 lists the estimated weight (in kilograms) of avocados shipped to California wholesale markets, packinghouses, and other distribution centers over the 8-mo sample period.

Identification of Armored Scale Species. The CDFA identification of armored scales entering California on Mexican Hass avocados February–July 2007 gave us an

Table 2. Numbers of 11.3-kg cartons of Mexican Hass avocados shipped into California over 8 mo (September 2007–April 2008)[a]

Fruit size[b]	No. cartons	Approximate no. fruit
32	14,821	474,272
36	23,862	859,032
40	119,030	4,761,200
48	348,551	16,730,448
60	338,671	20,320,260
70	95,104	6,657,280
84	162,819	13,676,796
#2s (all sizes)[c]	58,114	3,486,840
Total	1,160,972	66,966,128

[a] Data source: California Avocado Commission, Avocado Marketing Research Information Center handler data (AMRIC). These data represent actual handler import records and thus underestimate the total volume shipped into California over this period.

[b] Fruit size refers to the number of fruit normally placed in each carton (i.e. size 32 is 32 fruit per carton) and thus the aproximate number of fruit is the fruit size × the number of cartons.

[c] Data are for all sizes of second grade fruit (#2s) combined.

Table 3. Weight (kilograms) of Mexican Hass avocados shipped into California over 8 mo (September 2007–April 2008)[a]

Month	Market destination				Total kg., all California	Estimated total no. fruit[b]
	Los Ang.	Sacr.	San Diego	San Fran.		
Sept. 2007	168,328	25,322	16,227	98,180	308,057	1,566,964
Oct. 2007	829,654	141,680	288,179	177,094	1,436,606	7,307,444
Nov. 2007	1,194,275	250,723	509,543	347,656	2,302,197	11,710,357
Dec. 2007	763,351	151,931	503,227	293,610	1,712,118	8,708,864
Jan. 2008	910,076	193,605	328,945	330,748	1,763,374	8,969,582
Feb. 2008	744,390	95,980	206,316	299,360	1,346,047	6,846,803
March 2008	1,439,770	390,600	239,474	307,229	2,377,073	12,091,225
April 2008	1,279,074	282,066	71,713	286,874	1,919,728	9,764,889
Totals	7,328,918	1,531,907	2,163,624	2,140,751	13,165,200	66,966,128

[a] Data source: California Avocado Commission, Avocado Marketing Research Information Center handler data. These data represent actual handler import records and thus underestimate the total volume shipped into California over this period.

idea of which species we might encounter on the sampled fruit. Digital photographs of the scale cover and body of each species, along with key diagnostic characteristics were provided to the secondary inspectors classifying the scales we found. When a potentially different scale species was seen by one of the secondary inspectors, it was viewed under a Leica MZ75 microscope (Leica Microsystems, Bannockburn, IL) at 50× magnification, via a Leica DFC290 Digital Firewire camera connected to a 45.7-cm (diagonal) computer monitor. Thus, all inspectors could simultaneously view the scale cover and exposed body of the scale, to discuss diagnostic characteristics and likely species determination.

To conduct molecular identifications, scale DNA was initially extracted using a nondestructive "salting-out" technique that had been used successfully in previous studies with Thysanoptera (Rugman-Jones et al. 2006); and subsequently using the quicker EDNA HiSpEx Tissue Kit (Saturn Biotech, Perth, Australia), following the manufacturer's protocol. Both methods leave the carcass of the insect intact in case there is a subsequent need to slide-mount it for morphological identification and to permit comparison of molecular and morphological characteristics. Polymerase chain reaction (PCR) was used to amplify a 750–800-bp (base pair, primers removed) section of the 28s large subunit of the ribosomal RNA gene. Amplification was performed in 25-μl reactions containing 2 μl of DNA template (concentration not determined), 1× PCR buffer (containing 2 mM $MgSO_4$; New England Biolabs, Ipswich, MA), 20 μM each dNTP, 1 μl of bovine serum albumin (New England Biolabs), 1 U of *Taq* polymerase (New England Biolabs), and 0.2 μM each of the primers 28sF3633 (5′-TACCGTGAGGGAAAGTTGAAA-3′; Choudhury and Werren 2006) and 28b (5′-TCGGAAGGAACCAGCTACTA-3′; Whiting et al. 1997). Amplification was performed in a Mastercycler 5331 or Mastercycler ep gradient S (Eppendorf North America, Inc., New York, NY) by using a touchdown procedure in which an initial annealing temperature of 58°C was decreased by 1°C each cycle until a final temperature of 50°C was reached and maintained for 30 cycles. After an initial 2-min denaturing at 95°C, each cycle of the PCR consisted of 30 s at 94°C, 50 s at the appropriate annealing temperature, and 1 min 15 s at 72°C, with a final extension of 10 min at 72°C. PCR products were visualized after electrophoresis on 1% agarose gels stained with ethidium bromide, cleaned using the Wizard PCR Preps DNA purification system (Promega, Madison, WI), and direct sequenced in both directions at the UC Riverside Genomics Institute Core Instrumentation Facility. Representative species-specific sequences are deposited in GenBank (see Table 4 for accession numbers; Benson et al. 2008). A BLASTN 2.2.19 search (Zhang et al. 2000) was used to compare sequences to existing Diaspididae sequences deposited in GenBank by Morse and Normark (2006).

Results

At least six described armored scale species and two other probably undescribed species (see below) were present in the samples collected during our survey (Table 4). We did not slide mount or sequence all 18,890 sessile scales found, so there could have been additional species present. The most common species found was the recently described *Abgrallaspis aguacatae* Evans, Watson and Miller (Fig. 1a and b) (Evans et al. 2009). The 28sD2 DNA sequence of this species (GenBank accessions FJ657531 and FJ040864) was 100% consistent over 54 voucher specimens that originated from six municipalities in Mexico. In turn, this sequence was at least 4% divergent from the 28sD2 sequences of all other diaspids previously deposited in GenBank by Morse and Normark (2006). Other described species identified by both morphological (by G.W.W.) and genetic methods (see GenBank accessions in Table 4) were as follows: *Abgrallaspis perseae* Davidson; *Acutaspis albopicta* (Cockerell) (Fig. 1c); *Diaspis miranda* (see below) (Cockerell) (Fig. 1d); *Hemiberlesia lataniae* Signoret (Fig. 1e); and *Pinnaspis strachani* (Cooley). Based on differing 28s sequence data, it seemed there were two additional cryptic "species" present in our samples, designated here as *Diaspis* sp. near *miranda* and *Hemiberlesia* sp. near *lataniae* (Fig. 1f). During the first three to four sampling periods, there were probably some visual species misidentifications. However, the secondary inspectors became better at correctly identifying scale species, with each comparison of digital photographs of scale covers

Table 4. Species of armored scale insects found on avocados from Mexico in this study and their known distribution in North America

Armored scale species	Specimen voucher no.[a]	GenBank accession no.[a]	Present in the U.S.	Present in California	Present in Mexico
Abgrallaspis aguacatae Evans, Watson and Miller[b]	AS278, AS281-283, AS286, AS290	FJ657531	No	No	Yes
Abgrallaspis aguacatae[c]	AS005, AS007-009, AS011-012, AS016-019, AS022-023, AS025, AS072	FJ040864			
Abgrallaspis perseae Davidson[a,c]	AS237, AS238	FJ040865	Yes[d]	No	Yes
Acutaspis albopicta (Cockerell)[a,c]	AS198, AS203	FJ040866	Yes[e]	No[e]	Yes
Diaspis miranda (Cockerell)[c]	AS333, AS334	FJ040867	No	No	Yes
Diaspis sp. near *miranda*[c,f]	AS324	FJ040868	No	No	Yes
Hemiberlesia lataniae (Signoret)[c]	AS211, AS240, AS250	FJ040869	Yes	Yes	Yes
Hemiberlesia sp. near *lataniae*[c,f]	AS142, AS160, AS313-315, AS322, AS328	FJ040870	No	No	Yes
Pinnaspis strachani (Cooley)[c,g]	AS201	FJ040871	Yes[h]	No	Yes

[a] For the listed species, the underlined voucher number for the slide mounted scale carcass deposited in the collection at the California State Arthropod Collection, Plant Pest Diagnostics Center, Sacramento, CA corresponds to the listed accession no. for the 28s sequence deposited in GenBank.
[b] Morphological identification by Evans et al. (2009), with voucher specimens deposited in the National Museum of Natural History, Washington, DC, and California State Arthropod Collection.
[c] Morphological identification by G.W.W., with voucher specimens deposited in the California State Arthropod Collection.
[d] *Abgrallaspis perseae* is reported as found on avocado in Georgia (Tippins and Beshear 1970) and Texas (Davidson 1964) in the United States.
[e] According to Gill (1977), *A. albopicta* was eradicated from nurseries in California and has not been seen since 1960. McDaniel (1968) lists it as being found in Texas.
[f] Genetic data suggest a species different from *Diaspis miranda* and *Hemiberlesia lataniae*, respectively.
[g] 28s genetic sequence identified in the present study matches a previous GenBank accession (DQ145378) for *P. strachani.*
[h] Cooley (1899) and Dekle (1954) list *P. strachani* as found on avocado in Florida in the United States.

and scale bodies, and with feedback from genetic sequencing and morphological identifications (by G.W.W.) of voucher carcasses.

Levels of Scale Infestation Seen on Mexican Hass Avocados. A single carton of Mexican Hass avocados was sampled from each of 140 trucks entering California in our survey. This resulted in a total of 7,343 avocados being inspected (Table 1). These 140 trucks contained a total of 189,325 cartons (mostly 11.3 kg each) of avocados with 10.4 million fruit (Table 1). In two cases (one carton each from the sample period ending 22-X-2007 and 8-I-2008), the sampled carton was of 17.0 kg (i.e., 150% the size of a standard 11.3-kg carton); and in three cases (one from 17-III-2008 and two from 14-IV-2008), the carton contained ten, 5-count bags of size 40 fruit (i.e., 125% the size of a standard carton). Ten of the 140 cartons sampled were labeled as organic avocados (one from 8-X-2007 and 5-XI-2007, two from 19-XI-2007, and three each from 10-XII-2007 and 17-III-2008). Table 5 lists sampling data from the 140 examined cartons.

Newly hatched, first-instar "crawlers" are responsible for the natural dispersal of armored scale insects. They are mobile until they find a feeding site; subsequent life stages of the female lack legs and are sessile (incapable of moving). In total, 5,247 live, sessile scales were found; of these, 89.5% were *Abgrallaspis aguacatae* (Table 5). In addition, 2,511 live eggs or crawlers were found, 70.9% of these were found under (in a few cases, near) the scale covers of *Abgrallaspis aguacatae* (this species births crawlers, not eggs). Table 5 lists *Abgrallaspis aguacatae* numbers separately from aggregate numbers for the other scale species. The scale covers of many of the species (such as *Hemiberlesia* spp.) were whitish and clearly visible on the green to black avocados especially in the case of large, adult female scales (Fig. 1e and f). However, *Abgrallaspis aguacatae* is relatively small (body length of a slide-mounted adult female ≈1.45 mm) and usually settles in depressions on the fruit; its brown scale cover blends with the color of the fruit skin, making it difficult to detect unless it is present in moderate to high numbers (Fig. 1b). Approximately one quarter of the fruit sampled (detailed records were not kept) had a significant amount of fruit surface lenticel damage after harvest, which resulted in 1–5-mm-diameter brown spots (Hoffman and Jobin-Décor 1999, Everett et al. 2008). Adult female *Abgrallaspis aguacatae* scale covers resembled the smaller fruit lenticel damage spots in color and size. Use of a dissecting microscope was essential in differentiating these scales from lenticel damage and in detecting the small first and early second-instar *Abgrallaspis aguacatae* scales.

Live eggs or crawlers were found in 84 of the 140 sampled cartons (60.0%). Fifty-eight cartons contained live *Abgrallaspis aguacatae* crawlers, 44 had live eggs or crawlers of other species of armored scale, and 18 cartons contained live eggs or crawlers of both *Abgrallaspis aguacatae* and at least one other armored scale species. Live, sessile armored scales were found in 129 cartons (92.1%); 93 had live *Abgrallaspis aguacatae;* 86 had live scales of at least one other species;

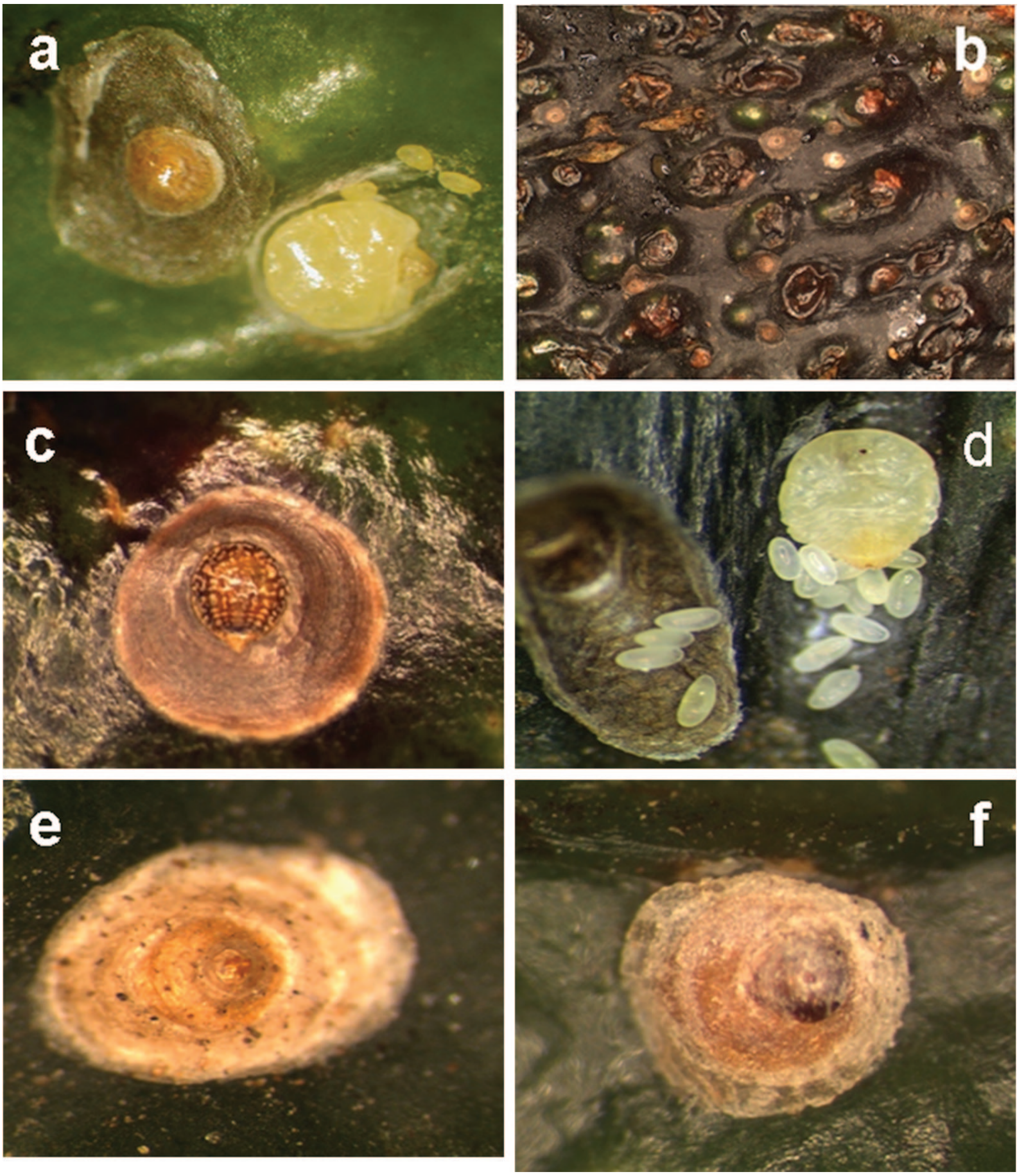

Fig. 1. Armored scales sampled on Mexican Hass avocados. (a) Displaced scale cover of *Abgrallaspis aguacatae* showing the exposed adult female scale and three crawlers (the mobile dispersal stage of the scale). (b) *Abgrallaspis aguacatae* scales are difficult to see on avocados because they are small, settle in depressions in the fruit, and blend in with the color of the fruit skin. (c) *Acutaspis albopicta* differ from other scale species on Mexican avocados by the dark brown color and rigidity of the scale cover. Sometimes the first-instar exuviae (cast skin, in the center of the scale cover) has a distinctive appearance, as shown here, but this is not always the case. (d) Displaced scale cover of *Diaspis* sp., exposed adult female, and 17 unhatched eggs. On Mexican Hass avocados, the turbinate body and v-shaped notch in the posterior end are diagnostic for *Diaspsis* spp. (e) *Hemiberlesia lataniae* occurs on avocados in California and Chile, and in low numbers on Mexican Hass avocados. Note the yellow color of the first and second-instar exuviae (cast skins) near the center of the scale cover of the adult female. (f) *Hemiberlesia* sp. near *lataniae* has a slightly different genetic sequence from latania scale (*H. lataniae*) and differs from *H. lataniae* by the darker, brown exuviae in the scale cover (compare with Fig. 1e).

and in 50 cartons there were live specimens of both *Abgrallaspis aguacatae* and other species of armored scale. Including dead scales, only two (1.4%) of the 140 cartons sampled failed to yield at least one fruit infested with an armored scale. This is remarkable as sometimes there were relatively few fruit in the carton (this varied from 24 to 92 fruit per carton with a mean [± SD] of 52.5 ± 13.9). On average, each inspected fruit was home to 0.71 live, sessile scales and 0.34 eggs and/or crawlers (all species combined).

Table 5. Number of armored scales found on fruit in 140 cartons of Mexican Hass avocados, estimated total number of scales on the 140 sampled trucks, and on all Mexican avocados reported by AMRIC entering California over the 8-mo period (September 2007–April 2008)

Scale species	Total no.fruit	No. live scales	No. live + dead scales	No. live eggs and/or crawlers
No. armored scales found on Mexican Hass avocados in 140 cartons (1 carton sampled per truck)				
Abgrallaspis aguacatae scale	7,343	4,694	18,890	1,781
Totals, seven other scale species		553	5,427	730
% *Abgrallaspis aguacatae*		89.5%	77.7%	70.9%
Totals, all armored scale species combined		5,247	24,317	2,511
Estimated totals for all fruit on the 140 trucks that were sampled				
*Abgrallaspis aguacatae*scale	10,416,464	6,614,949	24,244,876	2,234,389
Totals, seven other scale species		789,653	8,070,947	886,020
% *Abgrallaspis aguacatae*		89.3%	75.0%	71.6%
Totals, all armored scale species combined		7,404,602	32,315,823	3,120,409
Estimated totals for all Mexican Hass avocados entering CA over the 8-mo (Sept. 2007–April 2008)				
Abgrallaspis aguacatae scale	66,966,128	42,526,667	155,867,236	14,364,605
Totals, seven other scale species		5,076,581	51,887,095	5,696,109
Totals, all armored scale species combined		47,603,248	207,754,331	20,060,714

Abgrallaspis aguacatae seems to be generally distributed through most of the 14 Mexican municipalities authorized to export avocados to the United States (see below). The origin of two of the sampled cartons could not be identified because of the lack of a municipality code on the outside of the carton. Fruit in the remaining 138 cartons were harvested from 12 municipalities; none came from the Aciutzio or Madero municipality. For the other 12 municipalities, the percentage of cartons infested with at least one *Abgrallaspis aguacatae* scale averaged 87.1 ± 17.4% (± SD). The percentage of cartons infested with this scale from individual municipalities and sample sizes were as follows: Apatzingan municipality (100% infested, n = 2 cartons), Ario de Rosales (83.3%, n = 12), Los Reyes (100%, n = 4), Nuevo Parangaricutiro (72.7%, n = 11), Periban (100%, n = 15), Salvador Escalante (64.3%, n = 14), Tacambaro (87.5%, n = 8), Tancitaro (91.2%, n = 34), Taretan (100%, n = 5), Tingambato (100%, n = 3), Tinguindin (42.9%, n = 7), and Uruapan (95.7%, n = 23).

Data collected from the single carton sampled from each truck were extrapolated to the total number of fruit present on that truck, based on data from the Bills of Lading (Table 5; Fig. 2). The number of cartons on each truck varied from 80 to 1,680 (Table 1), and the estimated number of scales on each truck was calculated separately before calculating the totals given in Table 5. Based on this extrapolation, 52 of the 140 trucks contained >5,000 live *Abgrallaspis aguacatae* crawlers, 29 had >5,000 live eggs and crawlers of other scale species, and 69 trucks contained >5,000 live eggs and crawlers of some species of armored scale (i.e., 12 trucks had >5,000 live eggs and/or crawlers of both categories [*Abgrallaspis aguacatae* versus others] of scales). Ten trucks each contained more than an estimated 50,000 live *Abgrallaspis aguacatae* crawlers, with one truck containing an estimated 243,097 live crawlers (Fig. 2a). Twenty trucks each contained more than an estimated 50,000 live second and third instar female *Abgrallaspis aguacatae* scales and one contained an estimated 1.35 million such scales (Fig. 2b).

Sample data were also extrapolated to estimate the number of scales present on the total volume of Mexican Hass avocados entering California over the 8-mo sample period. There were ≈10.4 million fruit on the 140 sampled trucks (Table 1) and an estimated 67.0 million fruit entering California over this period (Table 2). Based on the samples from 140 trucks carrying an estimated 15.6% of the total fruit entering California over this period, a total estimated 47.6 million live sessile scales, and an additional 20.1 million live eggs and crawlers, entered California on Mexican Hass avocados over the 8-mo sample period (Table 5).

Discussion

Past Records of Armored Scales on Mexican Avocados. Examination of the published scientific literature suggests that limited research has been conducted on armored scales infesting avocados in Mexico. Some published records are likely erroneous but would be difficult to correct without voucher specimens for reference.

The 2004 Mexican Hass avocado risk assessment (APHIS 2004: Appendix A2, Arthropod Pest List), which lead to entry of fruit into California in 2007, listed 21 diaspidid taxa found on Mexican avocados. Four of these records were from the "PIN-309 port interception database"; the specimen was identified only to genus, and a footnote indicated "Further analysis not possible because species not identified". The remaining 17 taxa were based on published literature but for 15 of them, a footnote stated "Pest associated with plant part other than commodity, or in rotting fruit on ground." Only *Abgrallaspis perseus* (=*A. perseae*) and *Acutaspis albopicta* were listed as "Pest is known to commonly infest fruit." It is well known that many Diaspididae are found mainly on leaves and/or stems but rarely on fruit. The intent of the second half

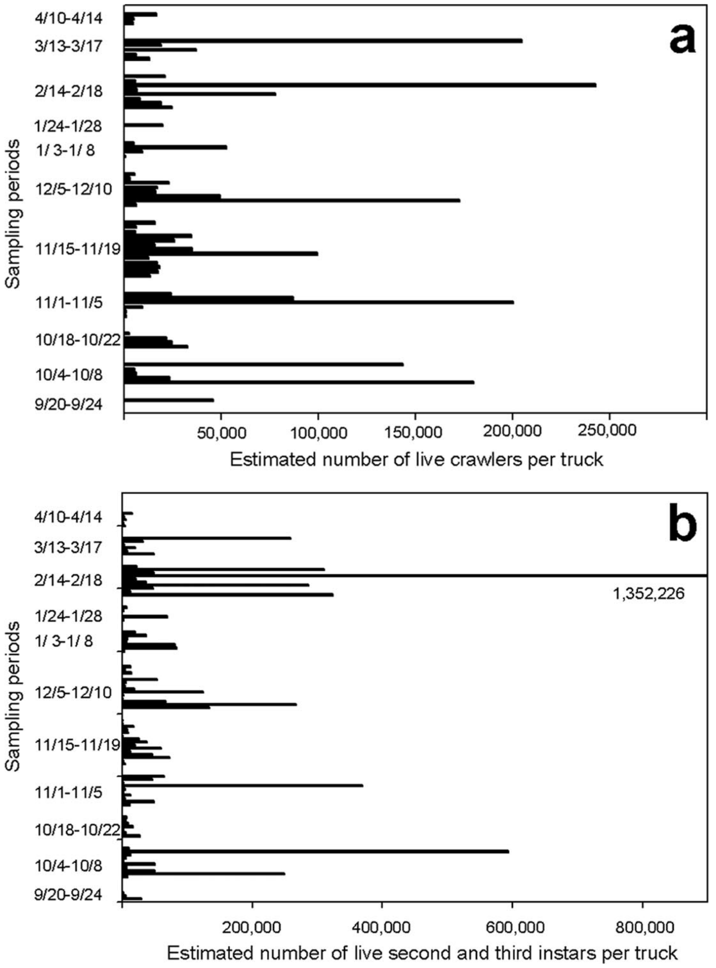

Fig. 2. (a) Extrapolated number of *Abgrallaspis aguacatae* crawlers for each of the 58 trucks in which live crawlers were found in the single carton sampled (mean = 15,960 live crawlers per truck over 140 trucks) listed for each of the 11 sample periods. (b) Extrapolated number of live second and third instar female *Abgrallaspis aguacatae* scales found on each of 94 trucks (mean = 42,157 over 140 trucks).

of the footnote ("or in rotting fruit on ground") is unclear, given armored scale biology and modes of dispersal. With the exception of adult males, armored scales are not sessile after the early part of the first instar. Scales found on fallen fruit suggest that most (if not all) of these fruit were infested while still on the tree, not after they fell to the ground. A rare exception to this might occur if crawlers produced by mature scales on fallen fruit infested clean, fallen fruit nearby.

We obtained a "Key to slide mounted Diaspididae found on Mexican avocado fruit by Donald R. Riley, 10 August 1998" (available from JGM upon request); this key is unpublished despite having been seen by a number of the scale taxonomists we contacted. Riley, a USDA–APHIS entomologist at Brownsville, TX, developed it for internal use by USDA–APHIS-PPQ port identifiers (J. W. Dooley, personal communication). The key separated eight species: *Abgrallaspis perseus* Davidson (now known as *A. perseae*), *Acutaspis albopicta, Diaspis boisduvalii* Signoret, *Hemiberlesia diffinis* (Newstead), *H. lataniae, H. neodiffinis* Miller and Davidson, *H. rapax* (Comstock), and *Quadraspidiotus* sp. (noted as undescribed). A ninth species, *Acutaspis perseae* (Comstock), was mentioned as seldom seen. It seems very likely that Riley's undescribed *Quadraspidiotus* sp. referred to *Abgrallaspis aguacatae.* Riley's key separated *Diaspis boisduvalii,* but the characters he used would identify any species of *Diaspis* as *D. boisduvalii* (including *D. miranda* and *Diaspis* sp. near *miranda,* found in our samples).

Apparently the key in Riley (unpublished) was widely distributed. It is therefore unclear why the APHIS (2004) risk assessment suggested that, of the nine species recorded by Riley from Mexican avocado fruit, six either were not present on fruit (*Diaspis boisduvalii* and *H. neodiffinis* were omitted from APHIS 2004) or were found only on rotting fruit on the ground (*Acutaspis perseae, Hemiberlesia diffinis, H. lataniae,* and *H. rapax*).

Table 6. Clarification of the identity of some of the armored scales on avocado in Mexico mentioned in scientific literature

Species name in the literature	Literature source	Comments
Abgrallaspis howardi (Cockerell)	Teliz (2000), APHIS (2004), Teliz and Mora (2007)	Junior synonym of *Diaspidiotus ancylus* (Putnam)
Chrysomphalus agavis (Townsend and Cockerell)	Ebeling (1959), Teliz (2000), APHIS (2004)	Probable misidentification; *C. agavis* only feeds on Agavaceae
Diaspidiotus perniciosus (Comstock)	Teliz (2000), APHIS (2004)	Probable misidentification of *Abgrallaspis aguacatae* Evans, Watson and Miller
Diaspis cocois/*D.* ca. a *coccois* (Lichtenstein)	Teliz (2000), APHIS (2004), Teliz and Mora (2007)	Probable misidentification; *D. coccois* only feeds on palms
Melanaspis aliena (Newstead)	Teliz (2000), APHIS (2004), Teliz and Mora (2007)	Now *Acutaspis aliena* (Newstead)
Velataspis dentate (Hoke)	Teliz (2000), APHIS (2004)	Misspelling of *Velataspis dentata* (Hoke)

Miller (1996) provided a comprehensive list of Diaspididae recorded from Mexico. Of the species listed, 40 (in 26 genera) have been recorded on avocado somewhere in the world, but not necessarily in Mexico (Watson 2002, Ben-Dov et al. 2008). Evans et al. (2009) provided an identification key to 53 species of armored scales (in 29 genera) recorded in the world literature as feeding on avocado and described and named *Abgrallaspis aguacatae.*

Teliz and Mora (2007) listed 14 armored scale species on avocados in Mexico. Discussion with Mexican scientists at the May 2007 Science Panel meeting in Los Angeles, CA, revealed that "*Quadraspidiotus perniciosus* (Comstock)" in Teliz and Mora (2007) was a misidentification of the newly described species, *Abgrallaspis aguacatae.*

The armored scale species listed in Miller (1996), Riley (1998), APHIS (2004), and Teliz and Mora (2007) do not agree. This may be because of faunal differences between years, misidentifications, and nomenclatural changes. Table 6 clarifies the identity of some of the species mentioned in Teliz (2000), APHIS (2004), and Teliz and Mora (2007).

Armored Scales Identified on Mexican Avocados in this Study. In our 8-mo study, eight probable species of armored scales were found on Mexican avocados. The study will continue for at least another year to obtain an expanded picture of species diversity over time, and to identify parasitoid wasps associated with the scales. Given the levels of scale infestation seen, and the volume of fruit entering California, the timely publication of the data herein was considered important even though the species identities of two of the (possibly undescribed) armored scales are unknown at present (*Diaspis* sp. near *miranda* and *Hemiberlesia* sp. near *lataniae*). In both cases, 28s sequences have been deposited in GenBank that can be used to identify these two taxa once their identity is clarified or they are described as new to science (Table 5).

Only one of the eight armored scale species found on Mexican avocados in this study, latania scale (*H. lataniae*), is known to be present in California. It was first reported there in 1928 and a survey of avocados in 1930 indicated that 38% of the 27,868 trees inspected were infested (Mackie 1931). Between 1928 and 1940, latania scale was the main arthropod pest on avocados in California (McKenzie 1935, Fleschner 1954). However, in subsequent literature there is little mention of its importance, probably because of excellent biological control by several coccinellids [including the indigenous *Chilocorous stigma* (Say)] and several parasitoids and predatory mites introduced to control California red scale [*Aonidiella aurantii* (Maskell)] on citrus (Fleschner 1954, Ebeling 1959, McMurtry 1972, Clausen 1978).

Of the seven exotic species found on Mexican avocados, it is not known whether *Abgrallaspis aguacatae, A. perseae, Diaspis* sp. near *miranda,* or *Hemiberlesia* sp. near *lataniae* can survive and reproduce on hosts other than avocado. Both *Abgrallaspis* species are known only from avocado (Ben-Dov 2008a, Evans et al. 2009). *Acutaspis albopicta* has been recorded from 14 host genera in 13 families (Ben-Dov 2008b). *P. strachani* is highly polyphagous, having been reported on hosts belonging to 68 plant families (Miller and Gimpel 2008a). Before this study, *D. miranda* was known only from the type material collected on leaves of *Achras sapota* L. in Mexico (Miller and Gimpel 2008b). The morphology of the *D. miranda* specimens we found on avocado fruits differed slightly from the type material, possibly because of host and substrate differences. Morphology in some armored scale species can vary according to characteristics of the plant surface on which they develop; for example, Stannard (1965) showed in *Diaspidiotus ancylus* (Putnam) that the number and shape of the pygidial lobes varied according to whether the insects developed on leaves or on bark.

Consideration of Risks. Hass is the predominant commercial variety of avocado grown in both Mexico and California; in a 2006 survey in California, >96% of commercial production was Hass (G. Witney, personal communication). By regulation, all avocado fruit from the Michoacan region of Mexico exported to the United States are of this variety. Hass has a relatively narrow environmental range in which it produces well. It therefore seems likely that *Abgrallaspis aguacatae* and the other six exotic species of armored scale on Mexican avocados would also do well on the same variety growing in California, and some of them (like *P. strachani*) may have much broader host ranges.

In Diaspididae, the first-instar crawler is the life stage that disperses the species. It is capable of crawling only short distances (Quayle 1911, Stofberg 1937), but passive movement via wind is a major means of dispersal. Although mortality is high, crawlers may be carried by wind a few meters to several kilometers and rarely, several hundred kilometers (Pedgley 1982, Mague and Reissig 1983, Washburn and Washburn 1984, Greathead 1990, Blank et al. 1990, Gullan and

Kosztarab 1997). Studying wind dispersal of California red scale, Willard (1974) observed that it "could in fact disperse quite rapidly . . . in spite of stringent restrictions on the movement of nursery stock, fruit and containers . . . New outbreaks of scale frequently occurred in orchards widely separated from previous infestations. Usually, once established in an orchard, the scale spread rapidly from the primary infestation." In a separate study, Willard (1973a) found that the "times of emergence and settling ensures that most wandering occurs in the late morning when wind velocities are most favorable for dispersal". Willard (1973b) also studied crawler survival at various temperatures and humidities and concluded that the "long periods of survival of crawlers, even under extreme conditions to which they would rarely be exposed in nature because of their rhythm of emergence, leaves little doubt that they could withstand transport by wind over long distances even during hot, dry summer weather." Most importantly, he found that "Field experiments with sticky traps demonstrated that red scale crawlers and males were carried up to 312 m by wind from a scale-infested lemon orchard. . . . The use of potted lemon trees as traps demonstrated that crawlers carried by the wind are able to establish on a suitable host following dispersal" (Willard 1974). Where Mexican avocados are repackaged at California packinghouses, cull fruit are usually disposed of in a dumpster. Diaspidid crawlers are negatively geotropic (Greathead 1990) and may be carried by wind from the top of the dumpster to nearby avocado trees (Pedgley 1982, Washburn and Washburn 1984).

Dispersal of armored scales by wind may be supplemented by mechanical dispersal via passing animals such as birds, on which the crawlers may "hitchhike" (McKenzie 1935, UC-IPM 1991). There seems to be little empirical evidence that birds provide such a service; however, a more obvious animal vector of armored scales on a crop is humans. It is easy to imagine a scenario in which armored scale dispersal results from the inadvertent transport of crawlers by persons handling imported Hass avocados at ripening facilities or packinghouses or at roadside stands. Crawlers could contaminate the hands and clothing of persons handling fruit, who might later come in contact with suitable host plants (McKenzie 1935, UC-IPM 1991). Most California facilities handling Mexican avocados sell second grade or damaged fruit via "back-door sales." Roadside fruit stands selling avocados are often located beside or in avocado orchards. Persons buying such fruit provide another possible avenue for the initiation of a scale infestation.

For California, Dreistadt et al. (2008) stated that "Until the 1990s . . . invertebrates caused only the occasional problems in mature avocado groves." This changed dramatically after the accidental introduction of persea mite (*Oligonychus perseae* Tuttle, Baker & Abatiello) in 1990 and avocado thrips (*Scirtothrips perseae* Nakahara) in 1996. The California Avocado Commission estimated that in 2006, crop loss because of avocado thrips fruit scarring exceeded US$50 million (G. Witney, personal communication). Both these pests were undescribed at the time of their initial discovery in California and subsequently were found to be native to Mexico (Hoddle et al. 2003, Rugman-Jones et al. 2007). *Abgrallaspis aguacatae* was described only recently (Evans et al. 2009), and if it is accidentally introduced from Mexico, one can but hope that it does not follow this pattern of becoming a severe economic pest of avocados in California after being initially undescribed from its native range.

The impact of introduced scale insects (Superfamily Coccoidea) on U.S. agriculture was detailed by Miller et al. (2005). They listed 255 species of scale thought to be adventive in the United States, including 132 Diaspididae (51.8% of all adventive scales in the United States, whereas only ≈32% of all scales in the world are Diaspididae). The introduction of San Jose scale (*Diaspidiotus perniciosus* [Comstock]) into California was one of the primary reasons that Congress passed the U.S. Plant Quarantine Act in 1912 (Marlatt 1920). To enable the importation of Mexican avocados into the United States, USDA–APHIS worked with Mexico to develop an annual Work Plan (e.g., APHIS–SAGAR 1998) that detailed how avocados could be imported with presumed safeguards to avoid the introduction and establishment of quarantine pests in the United States. Mexican avocados were first allowed entry into the United States on 25 February 1997; the APHIS policy making armored scales on avocados nonreportable went into effect on 4 October 2000. Thus, the Work Plan was in operation for >3.5 yr before USDA–APHIS revised their policy such that armored scales on avocado fruits were no longer reportable.

The Work Plan (APHIS–SAGAR 1998) stated: "9.1. All pests found in Mexico during the operational phase of this work plan shall be identified by Direccion General de Sanidad Vegetal (DGSV) in Michoacan and, immediately after, turned over to APHIS for confirmation. If DGSV identifies the specimen as a non-quarantine pest, the orchard or packinghouse may continue to export. In cases where APHIS identifies that same specimen as a quarantine pest, the export certification shall be suspended immediately." This mechanism of avoiding the importation of quarantine level pests, i.e., the identification of such pests by DGSV and their passing on samples to USDA–APHIS with confirmation of pest identity, must have failed over this period. The 1998 Riley key used by APHIS port inspectors clearly lists the presence of an unidentified *Quadraspidiotus* sp. on Mexican avocados (likely *Abgrallaspis aguacatae*). *Abgrallaspis aguacatae* was present on our sampled fruit at an average level of 0.88 live insects per fruit (1,781 live crawlers and 4,694 live sessile scales on 7,343 fruit; Table 5).

The main argument of the pest risk analysis for armored scales by USDA (2007a) was not that this group of insects is harmless; in fact, they acknowledged that these species are ". . . capable of potentially serious consequences". This is one of the reasons why live exotic scales on propagative material remain classified as quarantine pests. Instead, USDA (2007a) argued that the chance that armored scales from fruit imported for consumption might establish a viable population on plants is low, because the crawlers are short-lived and are poorly able to disperse into the environment.

In the 140 cartons we sampled, there were 4,684 live female second- and third-instar scales in addition to live eggs and crawlers. These nonreproductive females may continue to develop and produce additional eggs and crawlers. No literature was found documenting how long armored scales can survive on harvested avocados; a reasonable estimate might be at least as long as the fruit remains in edible condition, which can vary widely from 5 to 21 d depending on ambient conditions (Arpaia 2006). Rather than producing offspring over a short period of time, armored scales produce 1–10 eggs daily, and females usually produce offspring continuously for several weeks until their death (Koteja 1990). Thus, it seems likely that additional crawlers could be produced by female scales on avocados for up to three weeks after the fruit arrives in California.

The "Law of Large Numbers" may be paraphrased to state that a rare event has a low probability of occurring in a small number of trials but a high probability of occurring in a large number of trials. At the May 2007 Science Panel meeting in Los Angeles, CA, the assumption was made that imported fruit follow a path of gradual dispersion from the point of import to the consumer's plate (APHIS 2007b). Where this assumption is true, we agree with the USDA–APHIS position that "armored scales as a group generally have limited natural powers of long-distance dispersal" (APHIS 2007a, p. 16) and present a low risk of establishment. However, Mexican avocados imported into California are not dispersed as soon as they enter the state; many shipments are reconcentrated at pack houses for repackaging and in many cases, scale-infested culls come into close proximity to avocado trees. For avocados, we believe the perceived low risk of pest establishment is overwhelmed by the sheer number of live exotic scales entering California. An estimated 47.6 million live scales and 20.1 million live eggs and crawlers entered California on an estimated 13.1 million kilograms of avocados over an eight-month period soon after the market was opened to shipments. The California Avocado Commission estimates that ≈36.3 million kilograms of Mexican Hass avocados will enter California in 2008–2009, i.e., approximately threefold the amount entering in 2007–2008 (G. Witney, personal communication, estimate for 1 November 2008–31 October 2009).

Based on the above-mentioned possible avenues of establishment, sheer numbers of live exotic scale crawlers and possible levels of armored scale polyphagy, we believe the threat of an invasive scale infestation originating from Mexican avocados on one of the many crops or plants found in California is real.

Implications for Californian Agriculture and Trade. Agricultural crops in California, especially perennials, have a history of challenges from diaspid scales and other Hemiptera (Ebeling 1959, Rosen and DeBach 1978, Gill 1997, Miller et al. 2005). In the event of accidental introduction of exotic armored scales to California, it is unknown to what degree they might be controlled by natural enemies already present. If chemical control of armored scales on avocados in California were required, this would be problematic because >90% of the commercial acreage is grown on steep hillsides. Almost all chemical treatments must be applied by helicopter, using low water volumes (935 liters of water per ha or less). Extensive experience with chemical control of California red scale in citrus groves on level ground suggests that helicopter spray coverage of hillside avocados would likely be relatively ineffective against armored scales, and very expensive. Thus, biological control would be the highly preferred and possibly the only efficacious method of control.

Some Diaspididae have very broad host ranges; for example, San Jose scale has been reported on hosts from 108 plant families (Ben-Dov 2008c), and *P. strachani* on hosts from 68 plant families (Miller and Gimpel 2008a). Other armored scale species have quite restricted host ranges (McClure 1990). *Abgrallaspis aguacatae* is a species new to science, so its biology and the extent of its host plant range are unknown. If *Abgrallaspis aguacatae* or any of the other Mexican scale species not present in California were to establish in the state, other crops as well as avocado might be damaged. In addition to the cost of control, the presence of these introduced pest species might well negatively impact Californian exports to other countries.

In our opinion, the risk presented by the import of large volumes of Mexican avocados infested with seven exotic species of live armored scales is unacceptably high. It threatens productivity and trade in Californian avocados and other farmed crops and could also impact endemic plants.

Looking Forward. In view of the importance of avocados to Mexico as an export commodity (219,364 metric tons exported to the United States in 2007 with a value of US$ 463.7 million; USDA–FAS 2008), it seems odd that surveys to determine the full diaspidid fauna present on the crop either have not been done or, if done, have not been published. Our findings suggest that a detailed survey of Hass avocados in both California and Mexico for armored scales and their parasitoids would be beneficial to both countries. Some of the natural enemies present in California might be valuable for control of armored scale pests on avocados in Mexico, and visa versa.

Based on our data, we believe the present policy of ignoring exotic Diaspididae on all commodities for consumption needs to be reexamined, in particular for the case of Mexican Hass avocados entering California. A general review of the means of determining pest status and the mechanisms used by the USDA–APHIS to evaluate pest risks is also warranted. We suggest that USDA–APHIS needs to reexamine its policies with regards to armored scales in accordance with its stated mission, "To protect the health and value of American agriculture and natural resources" (APHIS 2008).

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References Cited

[APHIS] Animal and Plant Health Inspection Service. 1995. Importation of avocado fruit (*Persea americana*) from Mexico, supplemental pest risk assessment. November 1995. USDA–APHIS–PPQ, Biological Assessment and Taxonomic Support, Riversdale, MD.

[APHIS] Animal and Plant Health Inspection Service. 2004. Importation of avocado fruit (*Persea americana* Mill. var. 'Hass') from Mexico, a risk assessment, November 19, 2004. USDA–APHIS–PPQ, Center for Plant Health Science and Technology, Raleigh, NC.

[APHIS] Animal and Plant Health Inspection Service. 2006. 12/2006 Rev. 11, USDA–APHIS–PPQ Secure Drive document.

[APHIS] Animal and Plant Health Inspection Service. 2007a. Phytosanitary risks associated with armored scales in commercial shipments of fruit for consumption to the United States (June 8, 2007 Revision). USDA–APHIS–PPQ, Center for Plant Health and Technology, Raleigh, NC.

[APHIS] Animal and Plant Health Inspection Service. 2007b. Phytosanitary risks associated with armored scales: Science panel meeting notes. May 8–9, 2007 Meeting, Los Angeles, CA. June 29, 2007 (Final Revision). USDA–APHIS–PPQ, Center for Plant Health and Technology, Raleigh, NC.

[APHIS] Animal and Plant Health Inspection Service. 2008. About APHIS. 1 September 2008. (http://www.aphis.usda.gov/about_aphis/).

[APHIS–SAGAR] Animal and Plant Health Inspection Service–Secretaria de Agricultura Ganaderia y Desarrollo Rural. 1998. Work plan for the exportation of Hass avocadoes from Mexico to the United States of America, July 1998. USDA–APHIS/Secretaria de Agricultura Ganaderia y Desarrollo Rural (SAGAR) represented by Direccion General de Sanidad Vegetal (DGSV), 7 July 2008 version.

Arpaia, M. L. 2006. Avocado postharvest quality, pp. 143–155. *In* G. Witney [ed.], Proceedings of the California Avocado Research Symposium. California Avocado Commission, Irvine, CA.

Bellamore, T. 2003. Mexican avocados: history . . . the full story. Calif. Avoc. Soc. Yearb. 86: 51–71.

Ben-Dov, Y. 2008a. ScaleNet, *Abgrallaspis perseae.* 19 August 2008. (http://www.sel.barc.usda.gov/catalogs/diaspidi/Abgrallaspisperseae.htm).

Ben-Dov, Y. 2008b. ScaleNet, *Acutaspis albopicta.* 18 August 2008. (http://www.sel.barc.usda.gov/catalogs/diaspidi/Acutaspisalbopicta.htm).

Ben-Dov, Y. 2008c. ScaleNet. *Diaspidiotus perniciosus.* 12 August 2008. (http://www.sel.barc.usda.gov/catalogs/diaspidi/Diaspidiotusperniciosus.htm).

Ben-Dov, Y., D. R. Miller, and G.A.P. Gibson. 2008. ScaleNet, Scales on a Host Query Results. 27 August 2008. (http://www.sel.barc.usda.gov/scalecgi/scaleson.exe?family=&scalefamily=Diaspididae&genus=Persea&scalegenus=&species=).

Benson, D. A., I. Karsch-Mizrachi, D. J. Lipman, J. Ostell, and D. L. Wheeler. 2008. GenBank. Nucleic Acids Res. 36: D25–D30.

Blank, R. H., M. H. Olson, and P. L. Lo. 1990. Armoured scale (Hemiptera: Diaspididae) aerial invasion into kiwifruit orchards from adjacent host plants. NZ J. Crop Hortic. Sci. 18: 81–87.

Choudhury, R., and J. H. Werren. 2006. Unpublished primers. (http://troi.cc.rochester.edu/~wolb/FIBR/downloads.html#protocols). University of Rochester. Document last modified 2006–04-19.

Clausen, C. P. [ed.]. 1978. Introduced parasites and predators of arthropod pests and weeds: a world review. U.S. Dep. Agric. Handb. No. 480.

Davidson, J. A. 1964. The genus *Abgrallaspis* in North America (Homoptera: Diaspididae). Ann. Entomol. Soc. Am. 57: 638–643.

Dreistadt, S. H., D. Rosen, and M. L. Flint. 2008. Integrated pest management for avocados. Statewide Integrated Pest Management Program, Univ. Calif. Agric. Nat. Res. Publ. 3503, Oakland, CA.

Ebeling, W. 1959. Subtropical fruit pests. University of California Division of Agricultural Sciences.

Evans, G. A., G. W. Watson, and D. R. Miller. 2009. A new species of armored scale (Hemiptera: Coccoidea: Diaspididae) found on avocado fruit from Mexico and a key to the species of armored scales found on avocado worldwide. Zootaxa 1991: 57–68.

Everett, K. R., I. C. Hallet, J. Rees-George, R. W. Chynoweth, and H. A. Pak. 2008. Avocado lenticel damage: the cause and the effect on fruit quality. Postharvest Biol. Technol. 48: 383–390.

Fleschner, C. A. 1954. Biological control of avocado pests. Calif. Avoc. Soc. Yearb. 38: 125–129.

Gill, R. J. 1997. The scale insects of California: Part 3. The armored scales (Homoptera: Diaspididae). California Department of Food and Agriculture, Sacramento, CA.

Greathead, D. J. 1990. Crawler behavior and dispersal, pp. 305–308. *In* D. Rosen [ed.], World crop pests, vol. 4A, Armored scale insects: their biology, natural enemies and control. Elsevier, Amsterdam, The Netherlands.

Griffin, R., G. Gordh, and R. Sequeira. 2007. Phytosanitary risks associated with armored scale insects (Diaspididae) on commercial fruit imported for consumption, Report of the Chair, May 29, 2007. U.S. Dep. Agric.–APHIS–PPQ, Center for Plant Health Science and Technology, Raleigh NC.

Gullan, P. J., and M. Kosztarab. 1997. Adaptations in scale insects. Annu. Rev. Entomol. 42: 23–50.

Hoddle, M. S., K. M. Jetter, and J. G. Morse. 2003. Introduction and establishment of exotic insect and mite pests of avocados in California, changes in sanitary and phytosanitary policies, and their economic and social impact, pp. 185–202. *In* D. A. Sumner [ed.], Exotic pests and diseases: biology and economics for biosecurity. Iowa State Press, Ames, IA.

Hoffman, P. J., and M. Jobin-Décor. 1999. Effect of fruit sampling and handling procedures on the percentage dry matter, fruit mass, ripening and skin colour of 'Hass' avocado. J. Hortic. Sci. Biotechnol. 74: 277–282.

King, L. K. 1995. Proposed Rule 7 CPR Part 319 [Docket No. 94-116-3], Importation of fresh 'Hass' avocado fruit grown in Michoacan, Mexico. Federal Register 60(127): 34832–34842.

Koteja, J. 1990. Embryonic development; ovipary and vivipary, pp. 233–242. *In* D. Rosen [ed.], World crop pests, vol. 4A, armored scale insects: their biology, natural enemies and control. Elsevier, Amsterdam, The Netherlands.

Mackie, D. B. 1931. A report of the coccids infecting avocados in California. Monthly Bulletin, Department of Agriculture, State of California. 20: 419–441.

Mague, D. L., and W. H. Reissig. 1983. Airborne dispersal of San Jose scale, *Quadraspidiotus perniciosus* (Comstock) (Homoptera: Diaspididae), crawlers infesting apple. Environ. Entomol. 12: 692–696.

Marlatt, C. L. 1920. Federal plant quarantine work and cooperation with state officials. J. Econ. Entomol. 13: 179–180.

McClure, M. S. 1990. Patterns of host specificity, pp. 301–303. *In* D. Rosen [ed.], World crop pests, vol. 4A, armored scale insects: their biology, natural enemies and control. Elsevier, Amsterdam, The Netherlands.

McDaniel, B. 1968. The armored scale insects of Texas (Homoptera: Coccoidea: Diaspididae). Southwest. Nat. 13: 201–242.

McKenzie, H. L. 1935. Life history and control of latania scale on avocado. Calif. Avoc. Assoc. Yearb. 20: 80–86.

McMurtry, J. A. 1972. The role of exotic natural enemies in the biological control of insect and mite pests of avocado in California, pp. 247–252. *In* C. J. Lovatt [ed.], Proc. Sec. World Avoc. Congr., Calif. Avoc. Soc., Irvine, CA.

Miller, C. E., A. S. Green, V. Harabin, and R. D. Stewart. 1995. Risk management analysis: a systems approach for Mexican avocado. USDA–APHIS, Riverdale, MD.

Miller, D. R. 1996. Checklist of the scale insects (Coccoidea: Homoptera) of Mexico. Proc. Entomol. Soc. Wash. 98: 68–86.

Miller, D. R., and M. E. Gimpel. 2008a. ScaleNet. *Pinnaspis strachani.* (http://www.sel.barc.usda.gov/catalogs/diaspidi/Pinnaspisstrachani.htm).

Miller, D. R., and M. E. Gimpel. 2008b. ScaleNet. *Diaspidiotus miranda.* (http://www.sel.barc.usda.gov/catalogs/diaspidi/Diaspismiranda.htm).

Miller, D. R., G. L. Miller, G. S. Hodges, and J. A. Davidson. 2005. Introduced scale insects (Hemiptera: Coccoidea) of the United States and their impact on U.S. agriculture. Proc. Entomol. Soc. Wash. 107: 1123–158.

Morse, G. E., and B. B. Normark. 2006. A molecular phylogenetic study of armoured scale insects (Hemiptera: Diaspididae). Sys. Entomol. 31: 338–349.

Pedgley, D. E. 1982. Windborne pests and diseases: meteorology of airborne organisms. Ellis Horwood, Chichester, United Kingdom.

Quayle, H. J. 1911. Locomotion of certain young scale insects. J. Econ. Entomol. 4: 301–306.

Rosen, D., and P. DeBach. 1978. Diaspididae, pp. 78–128. *In* C. P. Clausen [ed.], Introduced parasites and predators of arthropod pests and weeds: a world review. U.S. Dep. Agric. Handbk. No. 48.

Rugman-Jones, P. F., M. S. Hoddle, L. A. Mound, and R. Stouthamer. 2006. Molecular identification key for pest species of *Scirtothrips* (Thysanoptera: Thripidae). J. Econ. Entomol. 99: 1813–1819.

Rugman-Jones, P. F., M. S. Hoddle, and R. Stouthamer. 2007. Population genetics of *Scirtothrips perseae:* tracing the origin of a recently introduced exotic pest of California avocado orchards, using mitochondrial and microsatellite DNA markers. Entomol. Exp. Appl. 124: 101–115.

Shepherd, J., and G. Bender. 2002. A history of the avocado industry in California. Calif. Avoc. Soc. Yearb. 85: 29–50.

Stannard, L. J. 1965. Polymorphism in the Putnam's scale, *Aspidiotus ancylus* (Homoptera: Coccoidea). Ann. Entomol. Soc. Am. 58: 573–576.

Stofberg, F. J. 1937. The citrus red scale (*Aonidiella aurantii* Mask.). S. Afr. Dep. Agric. For. Sci. Bull. No. 167.

Teliz, D. [ed.]. 2000. El Aguacate y su Manejo Integrado. (The Avocado and it's Integrated Management). Mundi-Prensa. Mexico City, Mexico.

Teliz, D., and A. Mora [eds.]. 2007. El Aguacate y su Manejo Integrado. Segunda Edicion, Mundi-Prensa. Mexico City, Mexico.

Tippins, H. H., and R. J. Beshear. 1970. The armored scale insects (Homóptera: Diaspididae) of Cumberland Island, Georgia. J. Ga. Entomol. Soc. 5: 7–12.

[UC-IPM] University of California–Integrated Pest Management. 1991. Integrated pest management for citrus. University of California Statewide Integrated Pest Management Project Publ. 3303.

[USDA–FAS] U.S. Department of Agriculture–Foreign Agricultural Service. 2008. United States Department of Agriculture, Foreign Agricultural Service, U.S. Trade Imports–HS 10-Digit Codes. Foreign Agricultural Service. (http://www.fas.usda.gov/ustrade/USTImHS10.asp?QI).

Walker, G. P., J. G. Morse, and M. L. Arpaia. 1996. Evaluation of a high-pressure washer for postharvest removal of California red scale (Homoptera: Diaspididae) from citrus fruit. J. Econ. Entomol. 89: 148–155.

Washburn, J .O., and L. Washburn. 1984. Active aerial dispersal of minute wingless arthropods: exploitation of boundary-layer velocity gradients. Science (Wash., D.C.) 223: 1088–1089.

Watson, G. W. 2002. Arthropods of economic importance: Diaspididae of the world. An illustrated identification guide and information source. CD-ROM. Expert Center for Taxonomic Identification (ETI), University of Amsterdam, The Netherlands. (http://nlbif.eti.uva.nl/bis/diaspididae.php).

Webber, H. J. 1916. The avocado industry and the avocado association, presidential address. Calif. Avoc. Assoc. Ann. Rep. 2: 55–67.

Whiting, M. F., J. C. Carpenter, Q. D. Wheeler, and W. C. Wheeler. 1997. The Strepsiptera problem: phylogeny of the holometabolous insect orders inferred from 18s and 28s ribosomal DNA sequences and morphology. Syst. Biol. 46: 1–68.

Willard, J. R. 1973a. Wandering time of the crawlers of California red scale, *Aonidiella aurantii* (Mask.) (Homoptera: Diaspididae), on citrus. Aust. J. Zool. 21: 217–229.

Willard, J. R. 1973b. Survival of crawlers of California red scale, *Aonidiella aurantii* (Mask.) (Homoptera: Diaspididae). Aust. J. Zool. 21: 567–573.

Willard, J. R. 1974. Horizontal and vertical dispersal of California red scale, *Aonidiella aurantii* (Mask.) (Homoptera: Diaspididae), in the field. Aust. J. Zool. 22: 531–548.

Zhang, Z., S. Schwartz, L. Wagner, and W. Miller. 2000. A greedy algorithm for aligning DNA sequences. J. Comput. Biol. 7: 203–214.

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