California Avocado Society 2009 Yearbook 92:43-64

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Mitigating Invasion Threats to the California Avocado Industry through Collaboration

Legal imports of fresh avocado fruit entering the US including California are increasing steadily from several countries including Mexico, Chile, Peru, New Zealand and the Dominican Republic due to advertising and promotion under the Hass Avocado Promotion and Research Order, along with various import associations, realizing business opportunities. Another reason the US market is rapidly expanding is the growing U.S. Hispanic population that regularly uses avocados as a food item, as well as increasing overall consumer awareness that avocados are highly nutritious, tasty, versatile, and easy to prepare. The overall growth in demand for Hass avocados has long exceeded domestic production. California produces all the Hass avocados grown commercially in the U.S., but domestic production simply cannot meet demand (Anon, 2006). In 2009, approximately 901,000,000 pounds of Hass avocados were imported into the U.S. primarily from Mexico and Chile (Anon, 2010; Table 1) as compared to California's production of nearly 158,000,000 pounds in 2008 – 09 (Anon, 2010b).

In addition to established import sources, other countries including Colombia, Guatemala, South Africa, Spain, and Uganda are currently seeking entry into the U.S. market (USDA-APHIS, April 30 2010). There are other regions that will undoubtedly petition USDA-APHIS for market entry, such as additional states in Mexico (Nayarit, Jalisco, Colima, and the state of Mexico). This trend of increasing fruit importation into the U.S. and California specifically from overseas is unlikely to stop or reverse itself as long as market demand and good financial returns exist. Consequently, the California avocado industry needs to develop forward-leaning policies to simultaneously manage increasing import loads and the pest threats that will likely accompany an expanding pool of exporting countries that are both within (e.g., Mexico, and Central America) and outside (e.g., Uganda and Africa in general) the evolutionary area of origin of the avocado. Each exporting country presents a unique set of pest risks because invaders could be co-evolved specialists from the home range of the avocado that have a very limited host range, or generalist pests from within and outside the area of origin of the avocado that can feed and breed on avocado as well as pose a threat to other existing crops and native flora in the U.S.

Importations of fresh produce into any area carry with them an easily identifiable risk; the threat of accidental introduction of unwanted arthropod pests, phytopathogenic diseases or a combination of both (i.e. the pest threat is both a vector which is accompanied by the pathogen it spreads). An excellent example of this latter possibility is the vector-pathogen complex represented by the Redbay ambrosia beetle *Xyleborus glabratus* (Coleoptera: Circulolionidae: Scolytinae) and the laurel wilt fungus (Raffelea Lauricola) that is specific to native Lauraceae and avocados in the southeastern U.S.

To minimize threats to importing regions, risk management programs are run by regulatory authorities representing the trading partners. The goal is to identify potential invasion threats which may be documented officially in risk assessment evaluations with subsequent reports and analyses quantifying threat levels. The investigatory and evaluation processes at work here are the basis of biosecurity practices enacted under law by countries that want to enforce quarantine restrictions. The application of these laws is to impose phytosanitary regulations governing imports and exports of commodities to prevent unwanted pest introductions while minimizing restriction of free trade between cooperating nations. This is an international trend and overseen, in North America by NAPPO (North American Plant Protection Organization), and specifically in the U.S. by USDA-APHIS.

This approach has formed the foundation of USDA-APHIS's recent relaxation of importation restrictions of avocados into the U.S. The basis underlying this relaxation is the implementation of a systems analysis approach to identify and quantify pest risks and threats associated with imports. A systems approach is the integration of different pest risk management measures, of which at least two act independently, and which cumulatively achieve the desired theoretical level of phytosanitary protection (UN FAO, 2001). Therefore, efforts to manage identifiable risk and reducing its likelihood to avocado producing regions perceived to be at risk from imports of fresh fruit may be attempted in the following general ways:

(Tier 1) Pre-Harvest Orchard Inspections: Certified exporting orchards are subjected to a variety of periodic phytosanitary inspections that are intensified over the fruit production period when infestation risks are considered to be greatest, or ongoing year round surveillance monitoring for organisms of high invasion concern (e.g., fruit flies) in the localities were such orchards are located. When used together, these two strategies could, depending on the frequency, quality, and reliability of the inspection and monitoring programs, minimize the infestation risk of harvested produce destined for export. Part of this strategic management approach in this Tier could also include application of targeted pest management treatments (e.g., pest trapping and insecticide application programs). Long-term monitoring data from these programs could lead to designation of "pest-free" areas within producer countries.

(Tier 2) Protection of Harvested Product and Subsequent Product Inspections: Many systems approaches require that the harvested product be protected following harvest. An example of this approach is the postharvest handling requirements for 'Hass' avocados from Mexico. In this situation, picked fruit need to be transported to the packinghouse within a specified amount of time and then transferred to a section of the packinghouse which is screened to prevent subsequent fruit fly infestation. Additional pre and post-shipment inspections of the harvested product may also take place. In some situations, a subsample based either on a fixed number or percentage of the entire load may be cut and inspected to verify that shipments originating from certified orchards and packinghouses are free of pest and export-quality-certifiable. Suspect fruit may be held in rearing cages to verify that the product is not infested. Insects detected from fruit cutting or fruit holding must be reared to adulthood for identification to species, or if this is not possible, molecular analyses could be employed for identification. Identification efforts will reveal either a known entity or a pest species new to science, and a previously unrecognized invasion threat.

(Tier 3) Physical Commodity Treatments: In some situations, regulations may stipulate that a physical commodity treatment be applied prior to shipment arrival (some treatments are conducted in transit) into the U.S. (or movement within the U.S. in the case of fruit fly infestations in southern California). For example, as currently approved, the importation of Peruvian avocados into the U.S. requires that the fruit be subjected to a postharvest treatment to control the possibility of infestation by the Mediterranean fruit fly (*Ceratitis capitata* [Diptera: Tephritidae]). For the foreseeable future, all fruit imported from approved regions in Peru, will be subjected to methyl bromide fumigation, cold treatments, or a combination of fumigation and cold treatments.

(Tier 4) Proactive Monitoring in the Receiving Area: A final and logical tier for a risk management program is the establishment of a monitoring system for key pests of invasion concern in areas where establishment is most likely to occur because of the regular importation of large volumes of produce over long periods of time. These two factors, large volumes and regular arrivals over long periods of time, greatly increase the likelihood of invasive pest establishment. Increased establishment likelihood occurs because stochastic barriers that normally prevent small founding populations establishing, such as inhospitable climate or host plants being in an unfavorable state, will on rare occasions be conducive for the establishment of small pest populations. In the absence of proactive monitoring, establishment of incipient pest populations is more likely to occur because they will not be detected. Further, when incipient pest populations are small and highly localized, the possibility of eradication exists when early detections are made.

Proactive monitoring for invasive avocado pests in California is highly recommended because this producing region is susceptible to the successful establishment of exotic pests. San Diego County, for example, has abundant host plants in urban areas, it has the largest avocado production acreage in California, the climate is sufficiently moderate for most pests to survive year round, and there are many points of ingress (e.g., sea and container ports, airports, and several international and national border crossings). This suggestion that San Diego County is subject to high invasion risk from avocado pests has historical evidential support. San Diego County has been the focal point for the establishment of several invasive foliage feeding avocado pests in California which were likely introduced on avocado plant material smuggled in from Mexico. These pests include the red banded whitefly, *Tetraleurodes perseae* (Hemiptera: Aleyrodidae) which was detected in 1982; persea mite, *Oligonychus perseae* (Acari: Tetranychidae), found in 1990; avocado lace bug, *Pseudacsyta perseae* (Hemiptera: Tingidae); and *Neohydatothrips burangae* (Thysanoptera: Thripdae). The latter two pests were both detected in 2004 (Hoddle 2005). Other avocado production areas in California are not immune to invasion as initial establishment points such as the detection of avocado thrips, *Scirtothrips perseae* (Thysanoptera: Thripidae), in Ventura County in 1996 demonstrated. It is likely that fruit feeding pests could exhibit similar propensities to establish in areas of California that have extensive commercial production areas (and backyard plantings), moderate year round climates, and increasing levels of trade (see Table 1).

Minimizing Risk by Embracing the Detection and Identification Challenge Invasive Pests Pose

Invasive pests fall into two general categories, well known pests in their home ranges that may or may not have a documented history of global movement; and the wild cards, species either unknown to science or very poorly studied and not recognized as threats until they first establish outside of their home range and cause unprecedented problems. The California avocado industry has experienced both types of invaders. Species of avocado pests that were unknown until their first detection in the U.S. include *T. perseae* (red-banded whitefly), *O. perseae* (persea mite), and *S. perseae* (avocado thrips), while described avocado pests now resident in California include *P. perseae* (avocado lace bug) and *N. burungae.*

The exotic pests listed above that afflict California grown avocados are all leaf feeding pests, of which two, persea mite and avocado thrips, regularly cause producers serious management and financial problems. In comparison to foliar pests, management costs and crop losses would be orders of magnitude greater should specialist avocado fruit feeding insects like moths, weevils, or fruit flies establish in California. These specialist fruit feeding pests fall into the same two categories as the leaf feeding avocado pests. The first group, those that are problematic in their area of origin, include, the avocado seed moth, *Stenoma catenifer* Walsingham (Lepidoptera: Elachistidae), the large avocado seed weevils, *Heilipus* spp. (Coleoptera: Curculionidae), and the small avocado seed weevils, *Conotrachelus* spp. (Coleoptera: Curculionidae).

At least one of these well known fruit pests, *S. catenifer*, has demonstrated its ability to invade a new area, the Galapagos Islands after being accidentally imported from mainland Ecuador in infested Fuerte avocados in 2001 (Landry and Roque-Albelo, 2003). This pest has almost eliminated the locally-produced avocado crop in the Galapagos Islands thereby forcing greater reliance on imported fruit from the mainland which in turn increases the risk of additional invaders establishing in the Galapagos (Hoddle, 2010).

In response to this recognizable invasion threat posed by *S. catenifer,* significant effort and resources were invested in discovering, identifying, and synthesizing the sex pheromone of *S. catenifer* (Hoddle et al., 2009; Millar et al., 2008; Zou and Millar 2010). Field work was required to demonstrate efficacy (Hoddle et al., 2009) and fine tune operational parameters such as optimal lure type, trap height placement in trees, and number of pheromone traps needed per orchard independent of its size to reliably detect one male *S. catenifer* in one week of monitoring under varying levels of infestation (non-existent, low, and high levels of fruit damage) (Hoddle et al., 2010). This work on the sex pheromone of *S. catenifer* required about 12 months of team effort over a 2.5 year period in Guatemala. The product of this work, the pheromone, was the result of an excellent and innovative collaborative effort between the University of California, Riverside, the California Avocado Commission, and cooperating growers and grower organizations in Guatemala. In fact, this project on *S. catenifer* may actually be a first for a California fruit industry; the identification of a high risk invader and subsequent proactive efforts to develop a very sensitive monitoring and detection tool in advance of its potential establishment in an at risk region. The pheromone can also be used by regulatory agencies in exporting countries to demonstrate that certified (i.e., pest free) orchards are free of *S. catenifer*, and it can also be used for the rapid detection of incursions of this pest into California.

To this end, in February 2010, a 22 trap surveillance network was set up in California specifically to monitor for *S. catenifer*. Traps have been deployed in important major avocado production areas in San Diego County (an area identified as high invasion risk based on previous ease of establishment of leaf feeding pests), Riverside, Los Angeles, Ventura, and San Luis Obispo Counties. This detection network is supported, in part, by funding from the California Avocado Commission to implement completed research on the *S. catenifer* pheromone that was supported by industry funds.

In addition to identifying the sex pheromone of *S. catenifer*, other benefits from this project in Guatemala came to all cooperating parties, including a detailed analysis of the natural enemy fauna associated with the larvae of *S. catenifer* (Hoddle and Hoddle, 2008a), and an inventory of other moth species feeding on avocado fruit was prepared by rearing larvae inside fruit to adults (Hoddle and Hoddle, 2008b) in Guatemala. Two of these moth species were new to science, and were subsequently described and named by taxonomic experts with the USDA-ARS (Adamski and Hoddle, 2009; Brown and Hoddle, 2010). One of these two new moth species, *Histura perseavora* (Lepidoptera: Tortricidae), may have the potential to be a serious pest of avocados (Brown and Hoddle, 2010). As a potential invasive species, *H. perseavora* falls into Tier 2 (rearing of pests in fruit to adulthood for identification) above in the risk management hierarchy as it is a pest species that was unknown to science and not recognized as a threat until this work was conducted. Now, it is possible to identify *H. perseavora* as a quarantine pest because of its known propensity to attack avocados.

Consequently, these research products from the *S. catenifer* research project can be used to support different Tiers of the phytosanitary program described above. For example, the *S. catenifer* sex pheromone can be used in Tiers 1 (monitoring export orchards), and 4 (use in a proactive monitoring system in the importing country). The construction of a pest inventory associated with fruit in the exporting country of interest supports all tiers of the monitoring system, and is especially useful for identifying pests in Tier 2, the detection of larvae and subsequent identification of adults either reared from fruit held in emergence cages or from fruit cutting inspections. An additional benefit from survey work is the identification of the natural enemy fauna that is derived as a by-product of fruit pest identification work. Particularly valuable are data on the identities and impacts of natural enemies on key fruit pests, and locality information and time of year natural enemies were found. Together, this information could potentially save considerable time and money when developing a classical biological control program should one of these pests establish in a new area.

Extending the Benefits of Proactive Pest Monitoring Research – Solicitation of Active Cooperation with Nations with Existing and Potential Avocado Export Industries

From the scientific publications that have come from the *S. catenifer* project in Guatemala (Adamski and Hoddle, 2009; Brown and Hoddle, 2009; Hoddle and Hoddle, 2008a, b, c; Hoddle et al., 2009, 2010; Millar et al., 2008; Zou and Millar, 2010), regulatory agencies now have an excellent base from which to assess the risks posed by moths that could be associated with exports of avocado fruit from countries within the native range of this plant and for developing monitoring and certification programs for these fruit infesting pests. Guatemalan growers have benefited because they now have available to them the sex pheromone of *S. catenifer* for monitoring and managing this pest, detailed information on the natural enemy fauna associated with the larvae of this moth, and an inventory of avocado fruit feeding moths, including two newly described species, that will help in pest identification and execution of management decisions.

Following the publication of work on the *S. catenifer* pheromone, SENASA Peru (Servicio National de Sanidad Agraria, the functional equivalent of USDA-APHIS in the US) extended an invitation to Hoddle to visit without restrictions, avocado orchards in Peru. SENASA officials organized a comprehensive visiting schedule, arranged transportation with local SENASA staff to access orchards, and coordinated with orchard managers and owners permission to visit and inspect groves in the coastal desert areas in the districts of Arequipa, Ica, Lima, and La Libertad that have been certified for Hass exports to Europe and the U.S. Visits to inspect non-certified orchards in the jungle areas of Chanchamayo in the district of Junin (around La Merced and San Ramón) and the district of Huánuco (around Tingo Maria) where pest problems are well recognized, in particular *S. catenifer*, were also organized. Inspections occurred over the period May – July 2010 which coincided with the Hass harvesting season. Financial support from the California Avocado Commission made this extended visit to Peru possible. The invitation from SENASA was timely because Peru commenced exports of Hass avocados from certified desert orchards to the U.S. in July 2010.

This invitation from SENASA allowed University of California researchers to deploy *S. catenifer* pheromone traps in export-certified and non-certified orchards, to present research seminars to SENASA workers in export areas on the bioecology of *S. catenifer* and how to use its sex pheromone for monitoring, to talk to SENASA staff and to growers about their pest issues, management and monitoring strategies (e.g., fruit fly programs and associated research projects [Proyecto Palto Hass in Huaral, Huara and Lima], Figures 1 – 3), to collect and photograph insect pests in orchards, and to rear insects developing inside damaged fruit collected from the Chanchamayo area for identification (Figures 4 – 8).

These two research projects in Guatemala and Peru on avocado fruit feeding pests have been extremely beneficial to both the California avocado industry and the host nations because of the building and cementing of new professional relationships and the generation of new information on fruit feeding insects that are of detection, monitoring, and management interest to all parties. In addition to pest moths, which this work has primarily focused on, other groups of fruit feeding insects (e.g., seed feeding weevils) are of quarantine concern, and the invasion threat associated with these pests has been recognized for a long time (Popenoe, 1919). It is surprising, given this long history of recognition, that greater efforts have not been invested in studying specialist avocado fruit pests, especially in the areas of origin of this plant that have export industries. For example, relatively little information exists on pest and natural enemy phenology, monitoring and control strategies, and possible alternative host plants that can support pests and natural enemies outside of commercial orchards. Further, details on the basic behavior, ecology, developmental and reproductive biology of key avocado fruit pests and their natural enemies could have been greatly improved especially if unrestricted collaborative investigations were established early between trading partners. It is of great significance that collaborative programs such as the ones completed in Guatemala and Peru have yielded significant new information to our understanding of avocado fruit pest complexes. These obvious research benefits could be extended to other avocado producing countries if strong collaborative partnerships could be established with current and potential exporting countries. Such proactive bi- or multilateral research projects would be extremely beneficial to identifying and mitigating invasion threats not only to the California avocado industry, but other countries with their own avocado industries that also import fruit from trade partners.

Future research efforts on avocado fruit pests aimed at proactively meeting the threats posed by invasive pests, that result in tangible outcomes similar to those achieved with collaborators in Guatemala and Peru, would be greatly enhanced from the development of research relations with other producer countries that are within the native (e.g., Mexico) or naturalized range (e.g., South America) of the avocado (Knight, 2002), or from countries where this plant itself is truly an exotic species (e.g., Uganda). Serious efforts should be made to forge these working relationships with partner nations.

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Table 1: The majority of countries that have avocado export rights to the US have substantially increased their volumes to the US over time. This trend is likely to continue as these countries maximize their export potentials and new countries enter the market place.

Country	Year of Entry into the US Market	Volume (MM[1]) Imported in First Year in US Market Access	Volume (MM) Imported in 2009	% Change in Volume
Mexico	1997	13.3	660.1	4863
Chile	1991	9.2	248.5	2601
Dominican Republic	2002	2.5	4.5	80
New Zealand	1999	3	0.6	-80

1MM = millions of pounds

Avocado importation data into the US shown in Table 1 was provided by AMRIC (Avocado Marketing and Research Information Center).

Figure 1. SENASA's Proyecto Palto Hass in Huaral, Lima Peru, is determining the risk fruit flies pose to Hass avocados destined for export. This project is being run jointly with the USDA.

Figure 2. In the Proyecto Palto Hass laboratory, experiments are conducted to determine fruit fly preferences for avocados, and whether or not fruit flies can oviposit and develop inside Hass avocados.

Figure 3. Proyecto Palto Hass is conducting replicated whole tree trials to verify the fruit preferences of fruit flies for oviposition. Inside these cages 15 fruit flies are released. Researchers inside the cages observe the flies and record their behavior and oviposition preferences.

Figure 4. Looking for pest infested avocados in a fruit stall in San Ramón, Junin, Peru. Fruit were collected and returned to the SENASA lab in San Ramon and held in cages for the rearing out of insects.

Figure 5. Pest infested avocados were collected from local fruit collection depots near La Merced, Junin in Peru. Local producers deposit fruit here where it is later shipped to Lima to be sold. SENASA field agents helped locate depots and infested fruit were returned to the SENASA lab in San Ramón for the rearing out of insects.

Figure 6. Avocados showing evidence of pest damage were collected from orchards in Peru and held in rearing cages for the emergence of insects.

Figure 7. A rearing laboratory was set up at the SE-NASA facility in San Ramón, Junin Peru. Insects and their natural enemies were reared from avocado fruit for identification.