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Lurkers on the Threshold: Potential New Fruit Pests for California Avocados

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Californian grown avocados are coming under increasing threat from exotic insect invaders. Since 1982, at least five new leaf feeding insects native to Mexico and Central America have established on avocados in California inflicting economic damage that ranges from the cosmetic (e.g., red banded whitefly, *Tetraleurodes perseae)* to the spectacular if control actions are not taken (e.g., persea mite, *Oligonychus perseae,* defoliations). Three of these five leaf feeders, *T. perseae, O. perseae,* and the avocado thrips, *Scirtothrips perseae,* were all species new to science at time of first discovery in the U.S.A. (Hoddle, 2004). So far, California grown avocados have escaped attack from a specialist fruit feeding guild of insects that feed internally on fruit in the home range of this plant in Mexico and Central America. This fruit feeding guild is comprised of weevils, fruit flies, and moths, a notorious group of pests that all feed within the enclosed protection of fruit, a feeding habit which greatly reduces the efficacy of chemically-orientated control measures.

Why are there no Avocado Fruit Feeding Insects in California?

This is an obvious question, and in my opinion, the reason why there are no internal fruit feeding avocado pests in California is largely, if not completely, due to a ban on the importation of fresh fruit and seeds from Mexico and Central America that has been in place in various forms since 1914 (CAC, 2004; Morse et al., 1995). Erosion of this importation ban began in 1997 when the USDA with accompanying Federal legislation permitted the importation of fresh avocados from certified areas in Mexico into 19 states in the northeastern U.S.A. By 2001, an additional 12 midwestern states were added to the list of US states in which it was legal to import and sell fresh fruit shipped from USDA certified zones in Mexico. Finally, in February 2007, the first shipments of fresh avocado fruit from Mexico arrived in California.

Interview statements from the USDA's Office of Regional and Bilateral Negotiations and Agreements voice the opinion that NAFTA was not the major force driving avocado fruit importations into the U.S.A. but likely helped facilitate dialogue in the process (Durant, 2007). Equally emphatic, have been statements from the Director of the Western

Hemisphere for the USDA's Animal and Plant Health International Services suggesting that avocado fruit smuggling poses a much greater risk to California avocado producers than does the importation of hundreds of millions of fruit from Mexico each year (Durant, 2007).

What is the Risk Posed to California Grown Avocados by Fruit Smuggled from Mexico?

I find this comment from the USDA that the risk of avocado fruit smuggling to California growers is a much greater threat for introducing fruit feeding pests than fruit importations very interesting for the following reasons. First, avocado fruit smuggling into southern California has undoubtedly been occurring for tens of years yet no fruit feeding pests have established permanent populations in California. The reasons for the lack of pest establishment most likely arises from the low and sporadic rate of "propagules" (i.e., infested fruit that may harbor weevils, fruit flies, or moths that could establish incipient populations) entering California, and surveillance and quarantine procedures at points of entry which intercept some, but not all, of the smuggled fruit.

Invasion success typically depends on the intensity of introduction pressure into new areas which is a relationship between incursion frequency and the number of pioneers entering each time. Frequently, successful establishment of invasive species occurs when founders are introduced repeatedly but discontinuously over long periods of time. Repeated introductions enhance the gene pool of founding populations and temporally stratified introductions are more likely to coincide with permissive environmental conditions (e.g., perfect climatic conditions or host phenology) that ease barriers to establishment. Biotic and abiotic barriers such as inappropriate growth stages of host plants (i.e., no fruit) or inclement weather prevent the majority of invaders from establishing. Thus over a long period of time the constant trickle of small quantities of smuggled avocado fruit into California harboring invaders have experienced major establishment barriers to overcome as they have failed to establish in the U.S.A.

Because fruit feeding pests have not yet established in California despite low volume fruit smuggling over many years suggests that establishment barriers via this route of introduction are immense and extremely difficult to circumvent. It is now likely that legalized imports of avocado fruit from Mexico will have an unintended consequence by providing a "concealing umbrella" for illegally moving much larger quantities of Mexican avocados than has previously occurred onto the Californian market from non-USDA certified areas. Once in California smuggled fruit can be repackaged and passed off as originating from certified areas. The possibility of profiting from illegally moving large quantities of fruit, despite the risks of being caught, will almost certainly encourage the large scale movement of smuggled fruit into California by ingenious ways. This type of smuggling occurs for many different commodities (e.g., fresh lychees) because when there is money to be made people will find a way around the system to profit illegally! This scenario of large-scale and professional fruit smuggling, possibly facilitated in part by the "concealing umbrella" of legalized imports, may increase the ease with which to obfuscate the uncertain origin of these fruit, and alters greatly the risk to California growers posed by smuggled fruit. Under these high volume conditions, smuggled fruit will pose the substantial risk to California avocado growers as predicted by the USDA.

What is the Probability that a New Fruit Feeding Pest Will Establish in California?

This brings me to the second point that fruit pests are estimated by the USDA to have a very low probability of establishing viable populations in California. The reason for this low probability is that there are a series of steps that an infested fruit must pass through without being detected and removed from the importation stream prior to entering a favorable environment for pest establishment. For example, a fruit with weevil or moth larvae needs to evade control and detection in orchards, packing houses, official inspections, and arrive in California in sufficient numbers for newly emerged adults to find each other to breed when environmental conditions and host plant growth stage are just right for establishment of their offspring.

Each of these steps has an estimated probability of occurrence, sometimes based on data and sometimes guessed at because data are not available for a particular step in the invasion process recognized by the path analysis. When the independent probabilities for each step of the invasion pathway are analyzed the chance of an unwanted hitchhiker arriving and establishing in California is very low. The USDA risk estimates for fruit flies in infested avocados entering suitable habitat in California is 0.0001-0.001 and for seed weevils and moths the estimates are 0.00005-0.0005 (Morse et al., 1995). These are extremely small numbers, which, in the USDA risk calculations, translate to time to establishment in California being > 1 million years for fruit flies and 1000-10,000 years for seed weevils and moths (Nyrop, 1995). Reanalysis of the probabilities used by USDA-APHIS using a more simplified statistical approach suggests that fruit flies could establish in 1,000-10,000 yrs, but seed feeding weevils and moths could establish within 3-5 years (Nyrop, 1995). Why are there big differences between the USDA-APHIS estimates and the Nyrop estimates for establishment times, especially for seed feeding weevils and moths in California? One reason pertains to the assumptions used in the analyses, another to the probabilities assigned to recognized factors but for which there are no data, and finally the choice of analyses that are performed. These statistical calculations are extremely complex and results can be influenced by best guesses and intuition when data are not available.

Another, perhaps more intuitive way of thinking about the probability of a rare event, such as avocado pest establishment in California is in the context of “The Law of Large Numbers.” This theory states that a **rare** event with a **low** probability of occurrence in a small number of trials has a **high** probability of occurrence in a **large** number of trials (Shermer, 2004). History suggests that in California the chances of an avocado fruit pest in smuggled fruit establishing are extremely low as this has not happened despite the long period of time that low volume and sporadic fruit smuggling has been occurring. So it is reasonable to assume that the probability of an avocado fruit feeding pest establishing in California is low and the reason for this is due to the low probability of a rare establishment event occurring because of low propagule pressure which is a function of fruit volume and the rate of infested fruit movement into California. With the legalization of fresh avocado imports into California this situation changes radically, no longer is propagule pressure low, it has increased instantly by orders of magnitude because millions of fruit are now regularly entering California over a prolonged period of time. Now the rare event of pest establishment has a much greater chance of happening (the establishment probability does not change) because the number of "trials" (i.e., shipment frequency and number of avocados per shipment entering California over the import season) has increased markedly.

A striking and memorable example of the "Law of Large Numbers" can be explained with the "one in a million" chance of a rare event occurring. Consider that for one eight hour period that you are active during the day a "one in a million" chance event could happen to you at any second. The number of events that could happen at any second in this eight hour period is about 30,000 per day (i.e., the number of seconds in this eight hour window) or ~1 ,000,000 per month. Therefore, the "one in a million" chance event can, on average, happen to you about once a month. When this scenario is extrapolated to the entire human population of the U.S.A., these rare "one in a million" events happen on average, 295 times a day, or about 8,850 times over a 30 day month (Shermer, 2004). Therefore, according to "The Law of Large Numbers" rare events (e.g., pest establishment) are not so uncommon when the number of times the event could happen is very large, such as the importation into California of hundreds of millions of avocado fruit from areas of the world with known fruit feeding pests.

Gathering Intelligence on the Enemy

A major problem with risk assessment reports that have been prepared by the USDA for avocado importations into the U.S.A., and California in particular, pertains to the information gathering process about pests. One aspect of a risk assessment report is the collation of information on known pests that attack the crop of interest. In this instance, fruit feeding insects. This inventory of identifiable pest threats can be prepared from multiple sources including: published reports in peer reviewed journals, books, trade magazines, industry brochures, web sites, and museum records. Sometimes these records may be erroneous, of poor quality, irretrievable, or information is simply not available. It is this last point, lack of information, which is most worrisome when risk assessment reports are prepared for avocados. As mentioned at the beginning of this article, three out of five leaf feeding pests that established on California avocados were species new to science until they were intercepted at border inspection stations (i.e., *O. perseae)* or established in California (i.e., *T. perseae* and *S. perseae).* Known entities such as the polyphagous thrips, *Neohydatothrips burungae* (synonym *N. signifier)* were not recognized as feeding on avocados until a thrips survey was conducted in Mexico and Central America (Hoddle et al., 2002). Unless thorough pest surveys are conducted in countries by highly trained and politically and economically neutral scientists many potential pest species will not be recognized as a threat until they surreptitiously invade a new area and cause problems. This anonymity in the searchable data bases greatly increases the "wild card" risk to the importing area as nothing is known about these potential invaders, their anonymity assures we do not know their identity (they may not even have a scientific name), let alone any aspect of the biology, ecology, and natural enemy fauna. The most recent example of an anonymous invader causing economic havoc to the California avocado industry was the avocado thrips, *S. perseae.* As it turned out after intensive survey work, this unknown pest was a relatively common thrips on avocados in its home range in Mexico and Guatemala but it had never been studied or recognized as a pest in its home range (Hoddle et al., 2002).

If the role of the USDA is being that of the primary guardian of U.S. agriculture and gate keeper for excluding invasive species and not that of a trade facilitator, then this agency, but more preferably independent contractors, should be surveying exporting countries to verify existing pest records, adding new species to the watch list, assessing damage, and determining levels of natural control and associated natural enemies. This work should be conducted over a lengthy period of time to capture the seasonality of pest and natural enemy population phenology and impacts on the crop.

What is Known About Avocado Fruit Feeding Insects?

Let us consider the risk posed to California by fresh avocado fruit importations. As part of the risk assessment procedure, data base searches will indicate that there are species of fruit flies, weevils, and moths that feed on avocado fruit. Solid data in the scientific literature on most of these pests is scant because they are poorly studied in their home countries, the distribution within a given country may be uncertain, along with alternative host use, seasonal phenology, the efficacy of control practices, natural enemies, and the exact number of species within recognizable genera. In lieu of good existing data, these identifiable impediments must have significant and adverse effects on the validity and reliability of any risk assessment program that has not had input from unbiased highly trained field staff that have conducted extensive surveys of the crop over a lengthy period of time for pests in the country of interest. The remainder of this article will describe the results of a five month survey for fruit feeding moths attacking avocados in Guatemala. The primary target of this program was the avocado seed moth, *Stenoma catenifer,* a well known pest of avocados in Mexico and Central and South America. Interestingly, field surveys quickly revealed that at least four to five other species of potentially previously unrecorded moths feed on avocados in Guatemala, and at least one of these, *Cryptaspasma* sp., is known from Mexico. At time of writing work was ongoing to ascertain the identity of these unknown moth species reared from avocados in Guatemala.

The Avocado Seed Moth, *Stenoma catenifer* Walsingham (Lepidoptera: Elachistidae)

Stenoma catenifer, the avocado seed moth, is a new world species that is thought to feed exclusively on the fruit and seeds of plants in the family Lauraceae. It has been recorded feeding on fruit of avocados (*Persea americana)* and the greenheart tree, *Chlorocardium rodiei,* an important timber tree in Guyana (Cervantes Peredo et al., 1999). *Stenomer catenifer* is a well known avocado pest attacking fruit in Mexico, Guatemala, Costa Rica, Panama, Bolivia, Colombia, Peru, Ecuador, Venezuela, and Brazil (Acevedo et al., 1972; Boscán de Martínez and Godoy, 1984). Avocados in Guyana are likely attacked as this moth has been recorded from fruit of greenheart in this country (Cervantes Peredo et al., 1999).

Damage to Fruit

Levels of *S. catenifer* infestation in avocados can be high. In some avocado growing regions of Brazil, 100% of the crop can be infested with *S. catenifer* (Nava et al., 2005a), and in orchards that are sprayed with broad spectrum insecticides 7-11 times over the course of a single growing season up to 60% of fruit can be infested with larval *S. catenifer* (Nava et al., 2005b). Consequently, this pest is considered to be one of the major impediments to commercial avocado production in Brazil (Nava et al., 2005a,b). In Venezuela, avocado fruit infestation with *S. catenifer* larvae can be as high as 80% (Boscán de Martínez and Godoy, 1982).

The major economic damage caused by *S. catenifer* is from larvae feeding inside fruit and subsequent damage to seeds and fruit pulp. Infested fruit hanging in trees with obvious *S. catenifer* damage are characterized by whitish exudate (i.e., perseitol, a 7 carbon sugar alcohol) that runs down the side of the fruit, accumulations of frass kick outs at the end of feeding galleries, and easily observable holes in the side of fruit (Plate 1, Figure 1). Opened fruit may show frass accumulation in the void that forms around the seed as the pulp separates from the seed as the fruit matures, seeds with feeding holes, or seeds completely destroyed by larval feeding. Complete seed destruction can occur in fruit that harbor more than two *S. catenifer* larvae. Surveys of Hass avocados collected from commercial orchards in Guatemala have revealed that 1-2 larvae per seed is the most common level of infestation. However, it is not uncommon to find the occasional seed with 3-4 *S. catenifer* larvae, and rarely 7-8 larvae may be found feeding in one seed (Hoddle unpublished data 2007). In Brazil >55% of avocado fruit that are attacked by *S. catenifer* are in the upper half of the tree (Hohmann et al., 2003). Surveys of damaged Hass fruit in Guatemala indicate that 8% of *S. catenifer* holes are in the top 1/3 of the fruit, 38% are in the middle third, and 54% are found in the bottom 1/3 of the fruit. Approximately 14% of fruit exhibit more than one *S. catenifer* hole (Hoddle unpublished data 2007). It is possible that fruit infested with *S. catenifer* larvae fruit may be prematurely aborted and will drop to the ground where larvae continue feeding in seeds before emerging from fruit to pupate in the soil.

Avocado varieties vary in their susceptibility to *S. catenifer* (Ventura et al., 1999; Hohmann, 2000). Attack rates may be as low as an average of 4.5% of fruit in Booth, intermediate in Fuerte at 23%, and high in Rincon at 54% damage (Hohmann et al., 2000). Field observations in 2007 in Guatemala around San Miguel Dueñas indicate that Hass avocados are readily attacked by *S. catenifer,* with up to 43% of randomly sampled fruit showing evidence of attack by this moth. Laboratory studies run in Guatemala that provided *S. catenifer* with a choice between criollo avocados and Hass fruit in large cages indicated that substantially more eggs were laid on Hass over a 3-4 day period. The reason for the preference *S. catenifer* exhibited for Hass avocados is undetermined but could be related to fruit qualities such as skin texture or perceived nutritive quality.

Developmental Biology

Adults. Adults moths are light tan color, and wings are marked with numerous black spots. The most characteristic marking on the forewings is the easily observable “C” shape of spots as the distal end of the forewings (Plate 1, Figure 2). Adult females are about 15 mm in length (tip of head to tip of wings) when in the resting position with wings folded across the dorsum. Wing span for females with forewings fully spread is around 28-30 mm in breadth. Males tend to be slightly smaller (2-3 mm shorter) than females and are similarly colored (Hoddle unpublished data 2007). *Stenoma catenifer* eggs are small and oval in shape (on average eggs are 0.59 ± 0.04 mm long and 0.38 ± 0.2 mm wide) (Cervantes Peredo et al., 1999).

Eggs. Eggs are laid singly and are initially white or pale cream when first laid and later darken as they mature. Female moths oviposit at night with peak oviposition occurring within four hours of darkness in which time 80% of eggs are laid (Nava et al.,

2005a). *Stenoma catenifer* females tend to lay eggs on rough surfaces and in crevices such as the fruit pedicel or necrotic spots on fruit (Hohmann et al., 2003).

Larvae. First instar larvae are pale cream to a very light violet in color. As larvae pass through successive instars they become progressively more violet in color. The final fifth instar (up to 25 mm in length) is characterized by having violet dorsal coloration (Plate 1, Figure 3) contrasting strikingly with a blue-turquoise colored ventral surface. When fifth instar larvae are ready to pupate the majority (>95%) will abandon the seed or fruit within which they are feeding, initiate active walking and climbing for approximately 12 hours, after which they will enter a quiescent period for another ~12 hours, often in a protected spot (e.g., under paper towel in the lab). During this quiescent period larvae will spin a very loose and fragile silk tent within which they will pupate. Oviposition studies in cages indicate that up to 68% of oviposited eggs can be laid on the branch to which the avocado fruit pedicel is attached (Hoddle unpublished data, 2007). In the laboratory, caged females can be induced to lay eggs on rough quilted paper towel as long as avocado fruit are provided as a stimulus to induce egg laying (Nava et al., 2005a).

Pupae. Pupae are “free” chrysalises that may be loosely attached with fine weak silk strands to a substrate but can be easily dislodge with gentle prodding. In the field, *S. catenifer* pupate in the soil at 0.5-2.0cm depth after leaving the fruit they were feeding in (Boscán de Martínez and Godoy, 1984). Young pupae are a striking turquoise blue in color and within 4-8 hrs of initial pupation this color becomes reddish-brown as pupae mature and melonize. Male and female pupae can be separated based on the presence of a small “suture” that divides abdominal segment 9 in the males (Cervantes Peredo et al., 1999). Some *S. catenifer* larvae (<5%) will pupate within the seed in which they were feeding (Hoddle unpublished data).

Natural Enemies

In Brazil, *S. catenifer* eggs are attacked by *Trichogramma* sp. and *Trichogrammatoidea* sp. parasitoids and up to ~60% of eggs can be parasitized. However, this level of attack is not high enough to prevent economic damage (Hohmann et al., 2003). Larvae in Brazil are attacked by a variety of hymenopterous parasitoids which can cause up to 30-40% parasitism. Larval parasitoids recorded from *S. catenifer* larvae include: *Cotesia* (*Apanteles)* spp. *Dolichogenidea* sp., *Hypomicrogaster* sp., *Chelonus* sp., and *Hymenochaonia* sp. (all Hymenoptera: Braconidae) (Nava et al., 2005b). Ichneumonids have also been recorded from *S. catenifer* larvae and include: *Eudeleboea* sp., and *Pristomerus* sp. (Nava et al., 2005b).

In Guatemala, the dominant larval parasitoid attacking *S. catenifer* is a *Cotesia* sp. (Hymenoptera: Braconidae) which can successfully parasitize >50% of larvae. Estimates of parasitism levels from surveys in Guatemala are affected by location and time samples were taken (Hoddle unpublished data 2007). Young *Cotesia* sp. larvae erupt out fifth instar *S. catenifer* larvae (Plate 1, Figure 4) and about 4-8 hours after emergence the majority of larvae have spun silk cocoons (Plate 1, Figure 5). Adult *Cotesia* sp. are small and black with orange legs and females can be easily recognized by the large ovipositor at the rear of the abdomen (Plate 1, Figure 6). A small number of *S. catenifer* larvae die in avocado seeds and parasitoids pupate within larval feeding galleries within the avocado seed. Adult parasitoids live for only about 1-2 days if they do not have access to food. Providing honey increases longevity of adult parasitoids to around 10 days (Hoddle unpublished data, 2007).

The results of this proactive forward-leaning work in Guatemala on *S. catenifer,* a serious fruit pest not yet presenting California, have provided biological and locality data on *S. catenifer,* facilitated the construction of a natural enemy inventory and preliminary investigations on parasitoid biology, allowed investigation of oviposition preferences for different cultivars of avocado fruit, and permitted investigations into mass rearing strategies in the laboratory for this pest. These types are studies are needed to better mitigate risk posed by invasive species that could attack avocados in California.

***Cryptaspasma* sp. (Lepidoptera: Tortricidae)**

Cryptaspasma sp. (Plate 2, Figure 1) was unexpectedly reared in fairly high numbers from avocados in Guatemala that were collected towards the end of the rainy season (late November 2006 and into early-mid December 2007). Unparasitized larvae that were reared through to adults were used to establish laboratory colonies for experiments. Fruit from which *Cryptaspasma* was reared included Hass and criollos, recently dropped fruit (seed still fully enclosed by pulp), exposed seeds picked up from the ground, and freshly harvested fruit purchased from roadside farmers.

***Cryptaspasma* sp. Biology and Natural Enemies**

Larvae of this moth feed on seeds (Plate 2, Figure 4) and cause damage to seeds in a manner similar to *S. catenifer* (Plate 2, Figure 5). Mature larvae will abandon seeds and form pupation chambers (Plate 2, Figure 6) and pupate either outside of the seed in protective areas (e.g., paper towel on the bottom of a rearing cage [Plate 2, Figure 7]) or within the seed (Plate 2, Figure 8). Pupal cases are easily identified by rows of small "teeth" on the dorsal surface of the pupal case and its obvious protuberance from the protective pupation site that results from adult emergence. The larval parasitoid *Pseudophanerotoma* sp. (Hymenoptera: Braconidae: Cheloninae), was reared from mature *Cryptaspasma* sp. larvae collected in Guatemala. Single parasitoid larvae would emerge from hosts, spin a cigar shaped cocoon (Plate 2, Figure 9), from which a golden orange parasitoid would emerge (Plate 2, Figure 10).

***Cryptaspasma* sp. in Mexico and Life Style Hypotheses**

The detection of a *Cryptaspasma* sp. in Michoacán Mexico in 2002, resulted in it being confused with *S. catenifer* and a subsequent investigation by USDA personnel ensued to clarify the identity of this moth (Brown and Brown, 2004). It was determined that *Cryptaspasma* was the culprit and a "brief" survey of fruit on trees in Michoacán did not locate larvae of this moth and it was subsequently declared to be a specialist of hard seeds of fallen fruit and did not pose a quarantine risk (Brown and Brown, 2004).

This hypothesis, that *Cryptaspasma* is a specialist of avocado seeds from fallen fruit lying on the ground was investigated in several different ways in Guatemala. As mentioned above, this moth was reared from very recently dropped fruit. These fruits were typically intact and immature, unripe and very hard (i.e., the fruit were still green). *Cryptaspasma* was reared from "hard green" dropped Hass fruit as small as 6-7 cm in length, green unripe criollos, or criollos showing signs of darkening indicating maturity in some varieties, exposed avocado seeds (Hass and criollos), and purchased criollos being sold by roadside farmers. Laboratory studies at ~25^{o}C indicated that it takes around 10 days for *Cryptaspasma* eggs to hatch and that this moth will lay eggs on exposed avocado seeds (Plate 2, Figure 2) and avocado fruit (Plate 2, Figure 3) under laboratory conditions. Experiments placing intact avocado fruit on the ground in orchards and observing at regular intervals indicated that intact dropped fruit have a very short life expectancy on the ground as the skin and pulp surrounding the seed is completely removed by animals (probably small mammals and birds) within 5-7 days. These two pieces of data, egg hatch times and fruit life expectancy on the orchard floor, would suggest that the probability of *Cryptaspasma* eggs laid on the skin of freshly dropped fruit would not survive long enough to hatch, burrow through the pulp, and then bore into the protective confines of the hard seed. Eggs laid on fruit hanging in trees would have ample time to hatch and larvae could bore through the pulp and enter the seed before fruit drop occurred and subsequent exposure to terrestrial vertebrates.

Another scenario that deserves consideration is the possibility that female *Cryptaspasma* do oviposit on fruit hanging in trees and the subsequent feeding activity of larvae, especially seed damage, causes fruit to abort and be dropped prematurely. This possibility would result in larvae being in seeds and escaping predation by fruit feeders on the ground, but give the appearance that this moth is a specialist feeder of exposed avocado seeds under trees. Laboratory studies did show that *Cryptaspasma* females would lay eggs on exposed seeds, so this possibility of attack under field conditions does exist and would support the Brown and Brown (2004) hypothesis.

Where the Brown and Brown (2004) "specialist of hard seeds of fallen fruit" hypothesis breaks down concerning *Cryptaspasma* sp. attacking avocados in Central America is the rearing of moths from purchased green unripened fruit from roadside farmers that showed no external damage of having either hit the ground after falling from a tree, or having been harvested from the ground after lying there for some time (remember that dropped fruit does not remain unmolested on the ground for long and the skin and pulp is quickly damaged and eaten by small animals.) The rearing of *Cryptaspasma* from undamaged purchased fruit and the demonstration that females of this moth will oviposit on undamaged fruit in experimental cages suggests that the possibility exists that *Cryptaspasma* females will lay eggs on fruit hanging in trees, and that feeding larvae could cause fruit to drop prematurely from trees, which collectively suggests that this moth has the potential to be a pest of avocados hanging on trees until conclusively proven otherwise.

In March 2007, experiments were undertaken in a commercial Hass avocado orchard in Guatemala to ascertain whether fruit on trees, freshly dropped fruit, or exposed seeds would be susceptible to attack by *Cryptaspasma* under field conditions. Unfortunately, three uncontrollable events transpired to thwart this investigation: (1) *Cryptaspasma* populations had dwindled to very low almost undetectable levels suggesting that it may be a species that does better when climatic conditions are not hot and dry for prolonged periods (mid-March is late into the dry season in Guatemala); (2) The section of the orchard that this *Cryptaspasma* trial was set up in was sprayed with insecticides, and (3) *S. catenifer* populations were high in the orchard and may have out competed *Cryptaspasma* at the time of year the experiment was set up. These types of experiments need to be conducted in the home range of *Cryptaspasma* to determine its status as an avocado pest. Evidence from the field and laboratory would suggest that the possibility exists that this moth could be an underappreciated pest of avocados hanging on trees.

Conclusions

Assessment and quantification of risk posed by potential invasive species is very difficult to measure and describe accurately. However, several steps can be taken to improve the quality of risk assessment reports:

1) In addition to conducting exhaustive literature surveys for potential pests, independent and neutral field operatives need to be deployed for prolonged periods in the country from which exports are anticipated. Comprehensive data sets are needed to better understand pest risk and population cycles and the relationship to crop phenology in exporting countries. In developing countries, a comprehensive and exhaustive understanding of the pest complex associated with export crops from which invaders could arise is largely lacking. This is easily illustrated with the establishment of three avocado leaf feeding pests in California that were previously unknown to science until arrival in the U.S.A.

2) Pathway analyses for quantifying invasion risk and pest establishment are imprecise and when data are not available best guesses are made. As with any model, the strength of the predictions rests with the quality of the data, the robustness of the model's assumptions, and the choice of analysis employed. Unilateral analyses by a single agency with an interest in obtaining a particular outcome for establishing risk for burgeoning markets are not adequate risk evaluations. Several independent researchers should be contracted to do these analyses and then resultant models and the subsequent scientifically defendable conclusions from these models should be subjected to rigorous and independent peer review by a qualified panel of neutral experts.

3) Increased scrutiny at points of exit (i.e., exporting country) and border entry are needed. For example, packinghouse inspections in the country of export are made by contract employees with known schedules and inspector presence is discontinuous. over the course of a day and a week. This situation provides ample opportunity for fruit of dubious origin (i.e., fruit from non certified orchards or undamaged fruit picked up from the ground [possibly common after wind storms]) to be packaged and certified as

originating from licensed or qualified areas. Inspections of produce at points of entry into the U.S.A. have diminished in importance under the Homeland Security Act. New legislation is needed to remove agricultural inspection services at points of entry from Homeland Security and elevate their importance, at the very minimum, to that of their pre-9/1 1 levels.

4) Fruit cutting is an imprecise method for determining infestation levels. Experience from Guatemala indicated that fruit that were cut open and examined for moth larvae were often considered clean when they were actually infested. The reason for these high numbers of negative detections occurred because larvae in many instances were too small to be detected in the pulp or the seed and feeding damage was not easily observable. The accuracy of fruit infestation estimates improved markedly when harvested fruit (especially hard immature green fruit) were held for ~10-14 days in cages and then manually "cracked" open and the seed and pulp examined for larvae. During this ~10-14 day holding period larvae in fruit had developed to a size that facilitated easy detection, and any eggs on the outside of harvested fruit had hatched and larvae had begun boring into fruit pulp causing observable damage. Consequently, fruit cutting does not measure the risk to an importing region posed by small undetectable larvae in fruit or unhatched moth eggs on the skin of fruit that could hatch in transit thereby allowing time for larvae to bore into fruit pulp and perhaps enter the seed by time of purchase and later use and subsequent discard into a Californian backyard by the consumer.

The avocado is an iconic Californian crop that is under threat from invasive species, increasing land and water costs, low priced imports, and political apathy. Following the legalization of avocado fruit imports into California, it will be very difficult to claim that the establishment of fruit feeding pests, should it occur, was not facilitated by the movement of hundreds of millions of avocados into California each year. Solutions to the identifiable weaknesses in the risk assessment procedures (e.g., lack of good biological data for key pests of interest and the unknown species, questionable model assumptions, and inaccurate pest detection estimates from fruit cutting) need to be resolved by an independent and neutral panel of experts. The "Law of Large Numbers" suggests that the likelihood of rare events occurring is actually very high when the number of times the event of interest (i.e., an imported fruit) can occur is also very high. In the unlikely event that avocado fruit feeding pests do not establish in California then mitigation plans in the area of export can be assumed to have been effective and could be an indication that such strategies function as intended.

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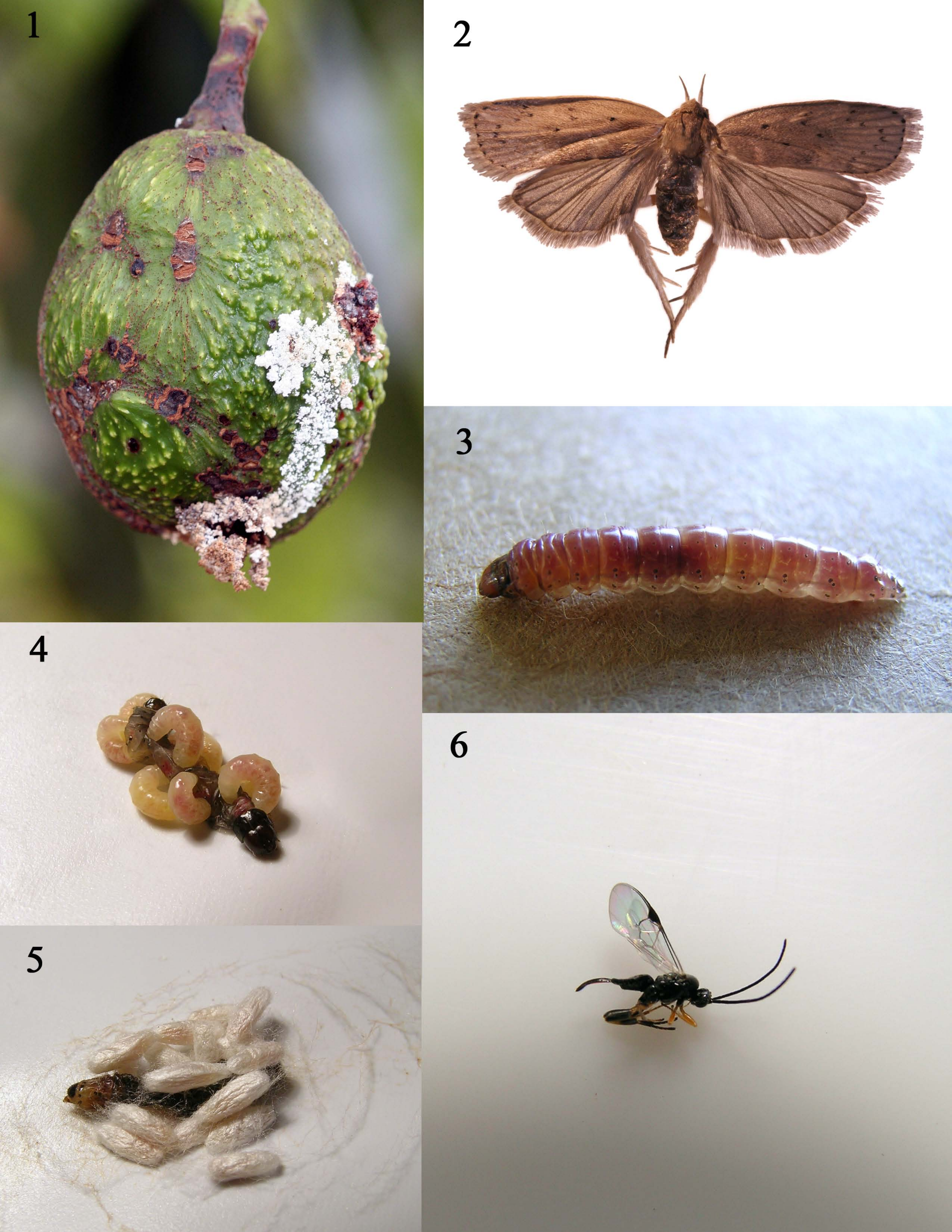
Figure Captions:

Plate 1. *Stenoma catenifer* damage to immature Hass avocado fruit (Fig. 1). An adult *S. catenifer* moth (Fig. 2). Fifth instar *S. catenifer* larva that has emerged from its avocado seed showing violet coloration (Fig. 3). *Cotesia* sp. larvae emerging from a fifth instar *S. catenifer* larvae (Fig. 4). *Cotesia* sp. parasitoid cocoons covering the withered cadaver of a *S. catenifer* larva. An adult female *Cotesia* sp. parasitoid (Fig. 6).

Plate 2. Adult *Cryptaspasma* sp. on an avocado fruit (Fig. 1). *Cryptaspasma* sp. eggs on an avocado seed (Fig. 2) and fruit (Fig. 3). *Cryptaspasma* sp. larva on an avocado seed (Fig. 4) and feeding damage to an avocado seed caused by *Cryptaspasma* sp. larvae (Fig. 5). *Cryptaspasma* sp. larva forming a protective pupation chamber in a piece of paper towel (Fig. 6), and an emerged *Cryptaspasma* sp. pupal case protruding from a paper towel (Fig. 7) and an avocado seed (Fig. 8). The cocoon (Fig. 9) of a *Cryptaspasma* sp. parasitoid, a *Pseudophanerotoma* sp., and the emerged adult parasitoid (Fig. 10).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