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DISCOVERY OF FALSE CODLING MOTH, *THAUMATOTIBIA LEUCOTRETA* (MEYRICK), IN CALIFORNIA (LEPIDOPTERA: TORTRICIDAE)

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Abstract.—The false codling moth, *Thaumatotibia leucotreta* (Meyrick), is one of the most destructive pests of avocado, citrus, and cotton in Africa. On July 24, 2008, a male of this species was identified from a pheromone trap located in Ventura County, California. Although larvae of *T. leucotreta* are frequently intercepted at U.S. ports-of-entry, primarily on bell peppers (*Capsicum* sp.), eggplant (*Solanum melongena*), and clementines (*Citrus* sp.), this represents the first North American record outside of a port or international commercial shipment. Additional individuals have not been recorded from California suggesting that this species is not yet established in the state. We provide descriptions, illustrations, and other information to help in the identification of this species.

Key Words: avocado, citrus, cotton, FCM, introduction, invasive, pest

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Thaumatotibia leucotreta (Meyrick), the false codling moth (FCM), is a native of sub-Saharan Africa. It is a highly polyphagous species, recorded on more than 50 species of plants in over 30 families (van der Geest et al. 1991, Brown et al. 2008), feeding primarily on the fruit. Many of its hosts are important cash crops, and larvae are known to cause serious damage to avocado, citrus, cotton, macadamia, mangoes, and many others (Reed 1974, van der Geest et al. 1991, Erichsen and Schoeman 1994, CPC 2007). Live and dead larvae are frequently intercepted at U.S. ports-of-entry, primarily on bell peppers (*Capsicum* sp.), eggplant (*Solanum melongena*), and clementines (*Citrus* sp.). During 2005, two live FCM larvae were found in California inside previously cold treated clementines from South Africa (USDA 2005). This event prompted a reevaluation and strengthening of the treatment protocol, and no further such detections have been reported.

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On July 24, 2008, a male false codling moth was identified from a pheromone trap located in Ventura County, California. This is the first record of a live adult *T. leucotreta* in North America. The purpose of this paper is to document the discovery of *T. leucotreta* in California and to provide descriptions, illustrations, and other information to help in the identification of this species.

Materials and Methods

The single specimen of *T. leucotreta* from California was dissected and compared to illustrations in Komai (1999) and authoritatively identified specimens from South Africa in the collections of the California Department of Food and Agriculture, Sacramento, U.S.A. and the Smithsonian Institution National Museum of Natural History, Washington, DC, U.S.A. Recently collected specimens from Kenya were used for wing pattern and morphological illustrations. Dissection methods essentially follow those presented by Brown and Powell (1991) except some preparations were not transferred to xylene and were mounted in Euparal (Bioquip Products, Rancho Dominguez, CA) rather than Canada balsam. Adults were photographed with a Canon EOS 40D digital SLR camera (Canon U.S.A., Lake Success, NY) mounted on a Visionary Digital BK Lab System (Visionary Digital, Palmyra, VA). Photographs of genitalia were taken using a Nikon DXM 1200 digital camera mounted on a Nikon Labophot2 compound microscope (Nikon Instruments, Melville, NY). Some photographs are a combination of several layers produced with Helicon Focus 4.80 software (Helicon Soft Ltd., Kharkov, Ukraine). All photographs were edited using Adobe Photoshop CS3 Extended (Adobe Systems Inc., San Jose, CA). Morphological terminology and wing pattern descriptions follow Komai (1999) and Gilligan et al. (2008). Natural history and host information are compiled from Brown et al. (2008), CPC (2007), Erichsen and Schoeman (1994), Komai (1999), Reed (1974), and van der Geest et al. (1991).

Results and Discussion

Nomenclature and Distribution

Argyroploce leucotreta Meyrick, 1913 was described from a female collected in South Africa. Although the species was long placed in the genus *Cryptophlebia* Walsingham, 1899 (e.g., Bradley et al. 1979, Daiber 1980, van der Geest et al. 1991), Komai (1999) recognized that a group of species traditionally assigned to *Cryptophlebia* belonged in *Thaumatotibia* Zacher, 1915, and he transferred *leucotreta* and its relatives to that genus (see Brown 2006 for a detailed explanation). Despite this action, the incorrect combination *Cryptophlebia leucotreta* (Meyrick) is still used in much of the contemporary economic literature.

The false codling moth has been reported as present in approximately 40 countries on the African continent and several islands, including Madagascar, Mauritius, Réunion, and Saint Helena (CPC 2007, EPPO 2007, van der Geest et al. 1991); it is not considered established outside of Africa (EPPO 2007). The first reports of *T. leucotreta* in Europe were from Finland in 1965 (Karvonen 1983, Lopez-Vaamonde et al. 2010), and it subsequently has been found in Israel, where it was declared "present, but of limited distribution, limited host range and subject to official control" by the Israeli Plant Protection and Inspection Services in 2003 (EPPO 2003, Hamburger et al. 2000).

False codling moth is one of the most commonly intercepted tortricids on pepper (Solanaceae: *Capsicum annuum* L.)

and eggplant (Solanaceae: *Solanum melongena* L.) at U.S. ports-of-entry (Brown 2006). Venette et al. (2003) report over 1,500 interceptions of "*C. leucotreta*" or "*Cryptophlebia* sp." since 1984 at a total of 34 U.S. ports. Over one-third of the interceptions were from John F. Kennedy International Airport in New York (Venette et al. 2003). Individuals have also been intercepted during quarantine inspections in Denmark, the Netherlands, New Zealand, and the United Kingdom (Bradley et al. 1979, Dugdale et al. 2005, USDA 2010).

Larval Hosts and Biology

Thaumatotibia leucotreta larvae are highly polyphagous and have been recorded feeding on more than 50 species of plants in over 30 families; a list of hosts compiled from Brown et al. (2008), CPC (2007), Reed (1974), and van der Geest et al. (1991) is presented in Table 1.

In Africa, false codling moth is a serious pest of citrus (*Citrus* spp. L.), cotton (*Gossypium* spp. L.), and avocado (*Persea americana* Mill.) (Erichsen and Schoeman 1994, Reed 1974, van der Geest et al. 1991). It has also been reported causing serious damage to corn (*Zea mays* L.), guava (*Psidium guajava* L.), macadamia (*Macadamia integrifolia* Maiden & Betche), mango (*Mangifera indica* L.), peach (*Prunus persica* (L.) Batsch), and other horticultural crops (CPC 2007, Erichsen and Schoeman 1994).

The biology of *T. leucotreta* has been thoroughly reviewed by Reed (1974; on cotton), van der Geest et al. (1991; on citrus), Erichsen and Schoeman (1994; on avocado), and Daiber (1979a, b, c; 1980; in controlled laboratory conditions); the following is a summary from those accounts. Development times, egg production, and adult lifespan are all highly temperature dependent. Daiber (1979a, b, c; 1980) and Venette et al. (2003) provide a thorough summary of *T. leucotreta* phenology and developmental thresholds.

Females deposit eggs singly or in small groups on the surface of smooth fruit. A single female may produce between 87–456 eggs in her lifetime (with a maximum of 799) (Daiber 1980). On fruit, larvae tunnel into the pith or feed beneath the surface. On cotton, larvae mine the wall of the boll and later move into the center of the boll to feed on the seeds. Larvae complete five instars. Last instar larvae exit the fruit or boll, drop from the host plant, and pupate in a silken cocoon in the soil, under leaf litter, or in bark crevices. The false codling moth is not known to diapause, and development is continuous; as many as 10 generations are possible per year in South Africa (Begemann and Schoeman 1999). The absence of a diapause may lead to host shifts and varied developmental rates in times of drought or when preferred host plants are unavailable.

Larvae cause significant damage by feeding directly on fruit or bolls. Feeding in citrus fruit can result in premature ripening and fruit drop as well as secondary infection by fungi. Larval feeding in cotton results in secondary infection by fungus and bacteria, causing rotting of the bolls. Feeding in avocado fruit results in lesions on the fruit and secondary infection by bacteria and fungi. Chemical control of this species is difficult due to the highly polyphagous, internal feeding larvae, and crop losses can be as high as 10–20% during serious citrus infestations (van der Geest et al. 1991). Control of false codling moth in South Africa is achieved through a combination of chemical control, mating disruption, attract and kill, natural enemies, and sterile insect technique (SIT) (Hofmeyr et al. 2005).

Table 1. Documented host plants for *T. leucotreta* (from Reed 1974, van der Geest et al. 1991, CPC 2007, Brown et al. 2008).

Family	Genus/species	Common name
Anacardiaceae	*Mangifera indica* L.	mango
Anacardiaceae	*Sclerocarya birrea* (A. Rich.) Hochst.	marula
Annonaceae	*Annona muricata* L.	soursop
Annonaceae	*Annona reticulata* L.	custard apple
Asclepiadaceae	*Calotropis procera* (Aiton) W. T. Aiton	roostertree
Bombacaceae	*Ceiba pentandra* (L.) Gaertn.	kapoktree
Bromeliaceae	*Ananas comosus* (L.) Merr.	pineapple
Capparaceae	*Capparis* L.	caper
Celastraceae	*Catha edulis* (Vahl) Forssk. ex Endl.	khat
Clusiaceae	*Garcinia mangostana* L.	mangosteen
Combretaceae	*Combretum apiculatum* Sond.	red bushwillow
Combretaceae	*Combretum zeyheri* Sond.	large-fruited bushwillow
Crassulaceae	*Crassula* L.	pygmyweed
Ebenaceae	*Diospyros* L.	diospyros
Ebenaceae	*Diospyros virginiana* L.	common persimmon
Euphorbiaceae	*Ricinus communis* L.	castorbean
Fabaceae	*Acacia karroo* Hayne	sweet thorn
Fagaceae	*Quercus* L.	oak
Lauraceae	*Persea americana* Mill.	avocado
Malvaceae	*Abelmoschus esculentus* (L.) Moench	okra
Malvaceae	*Abutilon* Mill.	mallow
Malvaceae	*Gossypium* L.	cotton
Malvaceae	*Hibiscus* L.	rosemallow
Myrtaceae	*Eugenia* L.	stopper
Myrtaceae	*Psidium guajava* L.	guava
Olacaeae	*Ximenia caffra* Sond.	sourplum
Oleaceae	*Olea europaea* L.	olive
Oxalidaceae	*Averrhoa carambola* L.	carambola
Poaceae	*Saccharum officinarum* L.	sugarcane
Poaceae	*Sorghum* Moench	sorghum
Poaceae	*Zea mays* L.	corn
Proteaceae	*Macadamia integrifolia* Maiden & Betche	macadamia nut
Punicaceae	*Punica granatum* L.	pomegranate
Rosaceae	*Prunus persica* (L.) Batsch	peach
Rosaceae	*Prunus* L.	plum
Rubiaceae	*Coffea arabica* L.	Arabian coffee
Rubiaceae	*Coffea* L.	coffee
Rubiaceae	*Vangueria infausta* Burch.	medlar
Rutaceae	*Citrus sinensis* (L.) Osbeck	navel orange
Rutaceae	*Citrus* L.	citrus
Sapindaceae	*Litchi chinensis* Sonn.	lychee
Sapotaceae	*Englerophytum magaliesmontana* (Sond.) T. D. Penn.	stem fruit
Solanaceae	*Capsicum annuum* L.	cayenne pepper
Solanaceae	*Solanum melongena* L.	eggplant
Stericulaceae	*Cola nitida* (Vent.) A. Chev.	ghanja kola
Theaceae	*Camellia sinensis* (L.) Kuntze	tea

Morphology

The morphology of *T. leucotreta* has been described in detail by many authors: Daiber (1979a) describes the egg; Williams (1953), Daiber (1979b), Komai (1999), Dugdale et al. (2005), and Timm et al. (2007) describe the larval morphology; Daiber (1979c), Komai (1999), and Timm et al. (2007) describe the pupa; and Meyrick (1913), Bradley et al. (1979), Komai (1999), and Dugdale et al. (2005) detail the adult morphology. Unless otherwise noted, the following abridged description is summarized from these sources or our own observations.

Egg.—The egg of *T. leucotreta* is flat and elliptical with a granulated chorion. Each egg is approximately 0.77 mm long by 0.60 mm wide. When newly laid, eggs are cream colored, eventually turning a reddish color with the embryo becoming visible prior to eclosion.

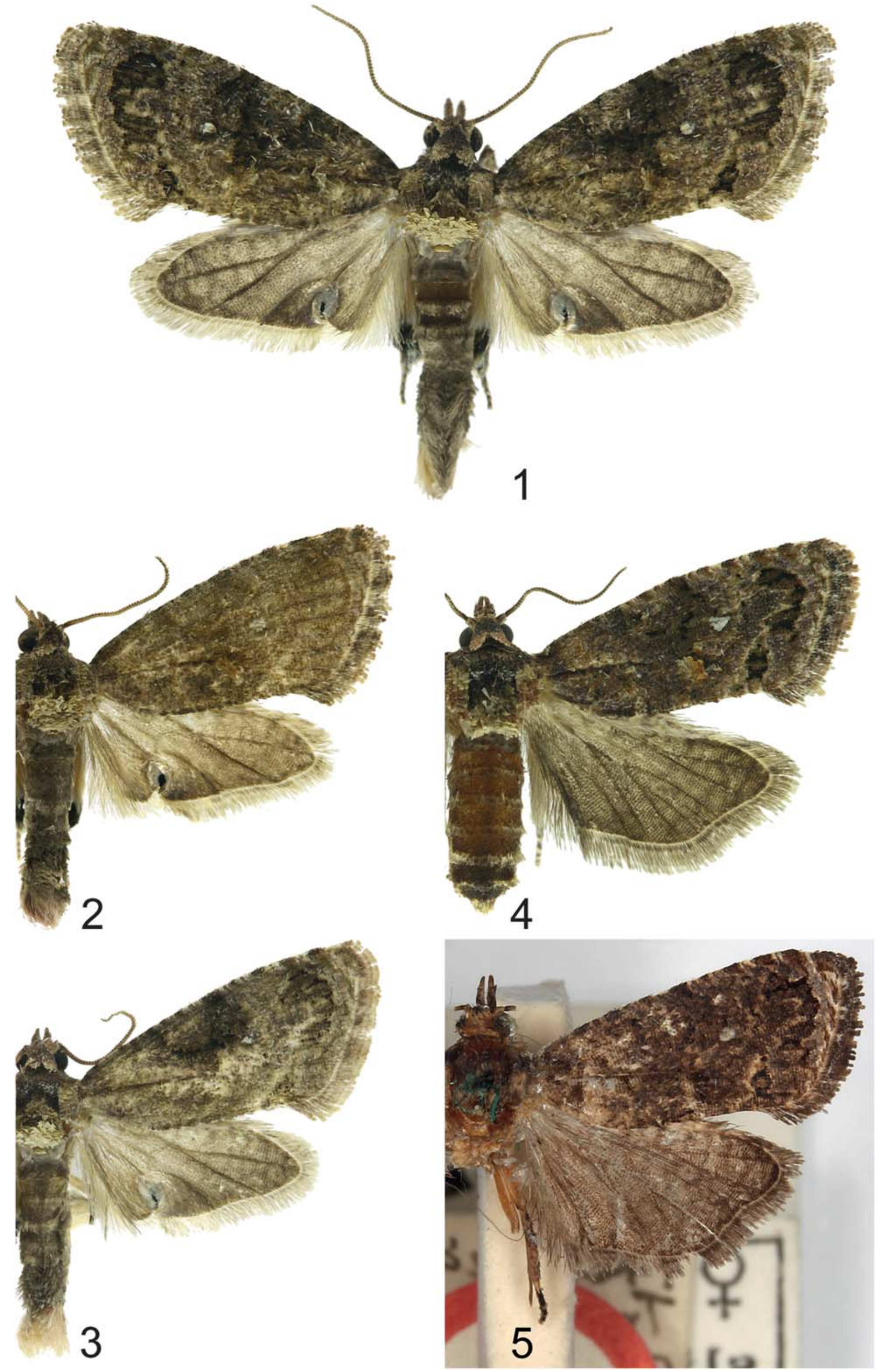
Larva.—First instar larvae are ca. 1 mm in length and are pale with dark pinacula. Mature larvae are ca. 12–18 mm long with a yellowish brown to dark brown head and prothoracic shield. The abdomen is orange to pink with large pinacula that are darker than the body color. Daiber (1979b) gives head capsule measurements for each instar.

Thaumatotibia leucotreta larvae can be distinguished from many tortricids in California by the following combination of characters: L pinaculum on T1 enlarged, extending beneath and beyond (posterad of) spiracle; D1 and SD1 on A9 on same pinaculum, separate from D2; L group on A9 trisetose; anal comb present with 2–10 teeth. Other larval characters of *T. leucotreta* include: SD2 on A1–8 highly reduced or appearing absent; SV groups on A1, 2, 7, 8, 9 with 3:3:2:2:1 setae; spiracle on A8 displaced posterad of SD pinaculum; D2 setae on A9 on shared mid-dorsal "saddle" pinaculum; V setae on A9 slightly farther apart than those on A8.

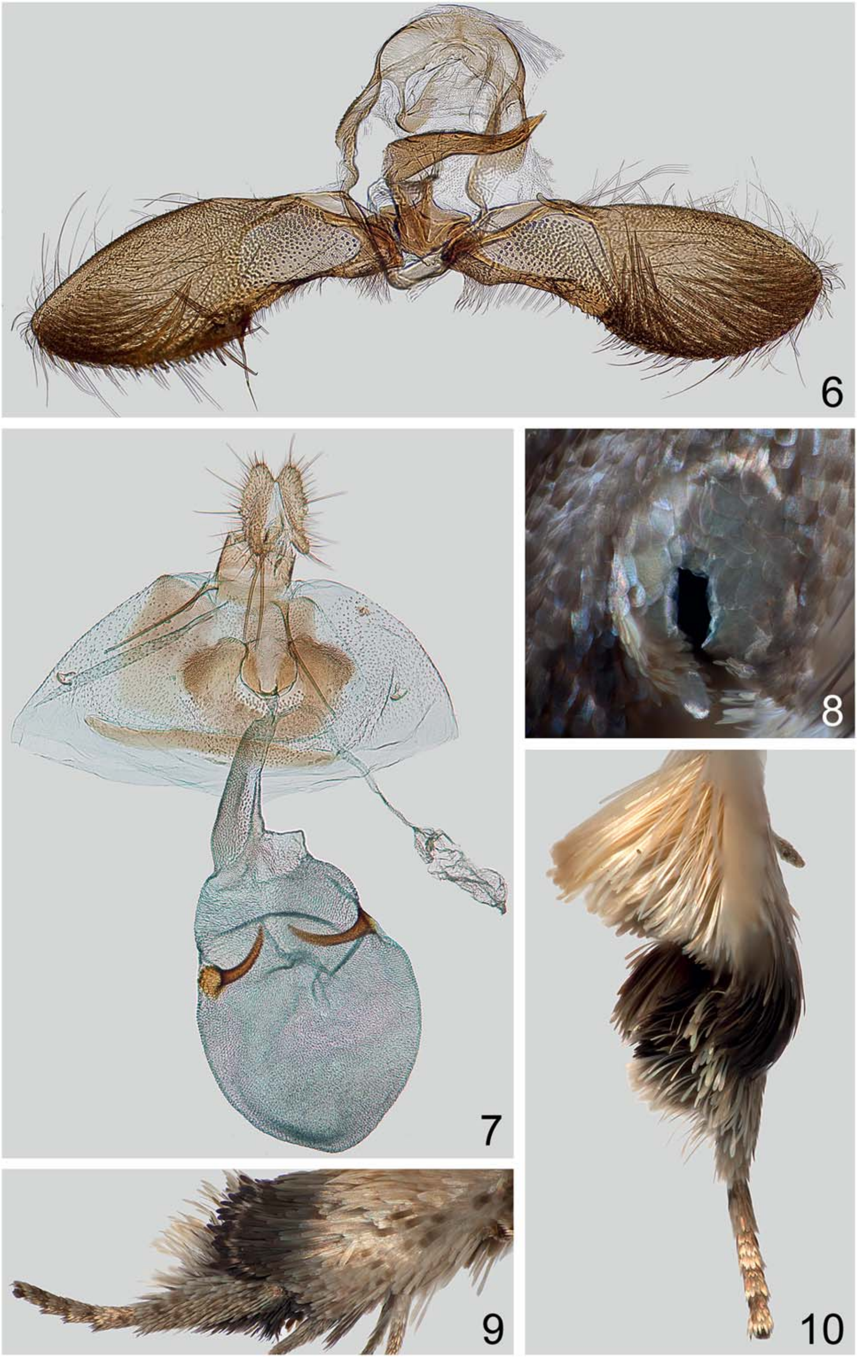
The larval characters listed here are not completely diagnostic, and *T. leucotreta* larvae are difficult to separate from Cochylini larvae, which can share the same set of character states (e.g., enlarged L-pinaculum on A9, spiracle on A8 displaced posterad, anal comb present). Two possible distinguishing features are SV counts of 3:3:2:2:2 and a bisetose L-group on A9 in many Cochylini (J. Brown pers. comm.). Should *T. leucotreta* become established in California, a DNA-based system may be necessary to assist with larval identification.

Pupa.—The pupa is pale yellowish brown, ca. 8–10 mm long, and is contained in a silken cocoon constructed with organic debris and soil particles. Important morphological features of the pupa include: segments A2–A7 with two rows of dorsal spines; segments A8–A10 with one row of dorsal spines except in males, where A8 has two rows of spines; A10 with two pairs of hooked setae and one pair of strong spines along anal rise.

Adult.—Adults (Figs. 1–5) are grayish brown to dark brown with forewing length of 7–8 mm for males and 9–10 mm for females. Males and females are sexually dimorphic, and the two differ in overall size, wing shape, and male secondary sexual characters. The male forewing is triangular, with an acute apex, while the female forewing is more elongate with a rounded apex. Male secondary characters include tufts of modified scales on the inner side of the hind tibia (Figs. 9–10), enlargement of the inner apical spur on the hind tibia with a batch of scales, and semicircular pocket of opalescent scales on the distal end of vein CuA2 on the hind wing (Fig. 8); the last character can be used to separate *T. leucotreta* males from all other North American tortricids. Forewing pattern



Figs. 1–5. Adult wing patterns, *T. leucotreta*. 1–3, Males; 4, Female; 5, Female holotype.



Figs. 6–10. Morphological details, *T. leucotreta*. 6, Male genitalia; 7, Female genitalia; 8, Pocket of opalescent scales on hind wing; 9, Hind tibia, lateral aspect; 10, Hind tibia, dorsal aspect.

can vary among individuals, especially in males where forewing color and pattern expression is not as consistent as in females. Most individuals exhibit a combination of four forewing pattern elements: a small white dot near the end of the discal cell; a patch of raised, usually rust colored scales near the middle of the wing; a distinct "question-mark-shaped" band of dark scales along the termen; and a semicircular band of dark scales in the middle of the costa. Male genitalia (Fig. 6) are characterized by a rounded tegumen lacking an uncus or socii, large rounded valvae, and a tapered aedeagus that is upcurved distally. Female genitalia (Fig. 7) are characterized by a semicircular sterigma, narrow ductus bursae, and large rounded corpus bursae with a pair of thorn-shaped signa.

Discovery of *Thaumatotibia leucotreta* in California

The first general survey for *T. leucotreta* in California was conducted by the California Department of Food and Agriculture (CDFA) in 2005 as part of the USDA's Cooperative Agricultural Pest Survey (CAPS) program. Pherocon® IIC traps (Trécé, Inc.) baited with *T. leucotreta* pheromone obtained from USDA were placed one per square mile in both rural agricultural land and urban residential properties, and traps were rotated to new locations every six weeks from May through October. The survey focused mainly on areas where primary hosts were most abundant and in areas identified as having a high risk for introductions. Similar surveys were conducted in 2006 and 2007, with 1000 traps deployed statewide. No individuals of *T. leucotreta* were detected in California during the 2005–2007 CAPS surveys.

In 2008, 911 traps were deployed in 26 counties from May through October as part of the CAPS false codling moth survey. A single male *T. leucotreta* was found in one of these traps on July 24, 2008 in a residential area near the Port Hueneme Harbor, Port Hueneme, Ventura County. In response, the CDFA and the USDA, in cooperation with the Ventura County Agricultural Commissioner, deployed an additional 1181 traps in a five-mile delimitation radius, at a density of 36 traps per square mile. In addition, 188 properties within a 400-meter radius of the detection site were searched during August and September, and host fruit was sampled from 56 properties. No additional *T. leucotreta* were detected in 2008. Delimitation trapping continued through June 2009, for three projected life cycles, and statewide detection trapping has continued during 2009 and 2010 through the CAPS program with no additional *T. leucotreta* captures.

Conclusions

Increased globalization and the expanded flow of international commerce have led to a concomitant increase in the transport, introduction, and establishment of plant and animal species around the world. The continuing introduction of nonindigenous (non-native) species into the United States is a significant and growing problem, costing taxpayers via lost agricultural productivity, expensive prevention and eradication efforts, environmental degradation, and increased health problems. The most recent study to attempt a nationwide estimate of the economic costs to the U.S. of nonindigenous species concluded that annual costs exceed $120 billion (Pimentel et al. 2005), which equates to costs of $1,100 per U.S. household per year (Lodge et al. 2006). The false codling moth is one of many tortricids considered to have high potential for invasion into the U.S. owing to its highly polyphagous habits, which include many important agricultural crops grown in the U.S., and its ability to thrive in climates such as those found in Florida, Texas, and California. This species is commonly intercepted at ports-of-entry in North America and Europe. Vigilance at these ports and early detection methods are critical to minimize the probability of this species' introduction and establishment in the U.S.

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