RESEARCH

Biology, Identification, and History of the Light Brown Apple Moth, *Epiphyas postvittana* (Walker) (Lepidoptera: Tortricidae: Archipini) in California:

An Example of the Importance of Local Faunal Surveys to Document the Establishment of Exotic Insects

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Abstract. The light brown apple moth (LBAM), *Epiphyas postvittana* (Walker), is a polyphagous species that is an important pest of apple, citrus, and grapes in Australia and New Zealand. The potential threat of LBAM to U.S. agriculture was recognized formally in 1957 when this species was included in the pest alert series "Insects Not Known to Occur in the United States" of the Cooperative Economic Insect Report. Although LBAM was excluded from a list of the top 100 most dangerous exotic pests of concern to the United States in 1973, most regulatory entomologists have continued to cite this species in risk assessments. LBAM was first discovered in the United States at Berkeley, CA, in 2006. Pheromone trapping efforts in 2007–2009 by the California Department of Food and Agriculture and the U. S. Department of Agriculture revealed its presence in Alameda, Contra Costa, Los Angeles, Marin, Monterey, Napa, San Benito, San Francisco, San Joaquin, San Luis Obispo, San Mateo, Santa Barbara, Santa Clara, Santa Cruz, Solano, Sonoma, Ventura, and Yolo counties, California. Previous surveys in California over the past 40 years, for LBAM in particular and for Lepidoptera in general, covering a variety of habitats including most of the known geographical range of LBAM, failed to detect this species. These negative data provide circumstantial evidence that LBAM arrived in California only recently. We provide descriptions and illustrations to help identify this newly arrived pest, along with a history of its discovery.

Epiphyas postvittana (Walker), the light brown apple moth (LBAM), is a polyphagous species that is an important pest of apple, citrus, and grapes in Australia and New Zealand (Bradley 1956). Because its potential introduction into North America could have a significant economic impact on U.S. agriculture, sporadic efforts over the past two or three decades have focused on its detection and exclusion from the United States. In 2006, one of the authors (JAP) collected two males of LBAM at blacklight in an urban area of Berkeley, CA. This discovery triggered a flurry of activities that documented the occurrence of this species over a broad latitudinal range in coastal central California.

In this article, we summarize the literature on the geographic distribution, hosts, life cycle, and morphology of LBAM to make this information available for anyone involved in the exclusion, detection, and identification of this species; to chronicle the discovery of LBAM in California and the events that followed; and to present information on previous surveys for the species (targeted and general) in order to better understand when the species arrived in California. We have not attempted to document pathways of LBAM entry into California, but rather we present a chronological overview of when specimens were first encountered in counties throughout the state.

Background on LBAM

Nomenclature

Epiphyas postvittana (Walker) was originally described in the genus *Teras* and subsequently was treated in *Tortrix*, *Archips*, *Cacoecia*, and *Eulia* by various authors. It was designated as the type species of *Austrotortrix* Bradley (1956), which was synonymized with *Epiphyas* Turner, 1927, by Common (1961). Now *Epiphyas* includes 40 species, all described from Australia.

Geographic Distribution

Epiphyas postvittana is indigenous to Australia. It occurs in all apple-growing areas in the southeastern part of that country, mainly along the coast and extending inland up to 200 miles. LBAM was introduced inadvertently into Tasmania and New Zealand (Bradley et al. 1973). It was first collected in the Hawaiian Islands in 1896 (Zimmerman 1978) and is now found at higher elevations on the islands, common only around Kula on Maui (D. Rubinoff, University of Hawaii, personal communication).

Meyrick (1937) recorded its discovery in the United Kingdom. Bradley et al. (1973) found that it was first established in Cornwall and subsequently spread throughout much of England. Bond (1998) first reported it from Ireland. An account of its history and distribution in the United Kingdom was presented by Baker (1968). It has been reported intermittently elsewhere in Europe, including in the Netherlands (Wolschrijn and Kuchlein 2006) and southern Sweden (Svensson 2009). Although it was reported from New Caledonia (Bradley et al. 1973), its presence in that country could not be verified by Suckling and Brockerhoff (2010).

Larval Hosts and Damage

Epiphyas postvittana is a polyphagous pest on pome and stone fruits and other horticultural crops. It has been recorded from >500 plant species in 121 families and 363 genera (Suckling and Brockerhoff 2010), although larvae prefer herbaceous plants over woody ones. A partial host list compiled from Danthanarayana (1975), Wearing et al. (1991), Venette et al. (2003), and CAB International (2007) is presented in Table 1. Larvae feed on the leaves, buds, flowers, and fruits of its hosts, but most economic damage is caused by injury on the surface of fruits under webbed leaves, causing scarring as well as providing a site for infection and rot. When left uncontrolled, larval damage to fruit crops in Australia and New Zealand during years of high population densities reached 70% (with a range of 5–70%) on crops such as apple, citrus, and grape (Danthanarayana 1975, Buchanan 1977, Wearing et al. 1991).

Life Cycle and Biology

Epiphyas postvittana completes 2–4 generations annually over much of its range, depending on temperature and latitude. Populations in California appear to undergo at least four generations; adults are active throughout the year. The upper and lower temperature thresholds for development in laboratory studies are 7.5 and 31°C; 20°C is the optimum for development, leading to a life cycle of 25 d (Danthanarayana 1975).

Eggs are deposited on smooth surfaces of host plant foliage, including leaves, stems, and fruit (Danthanarayana 1975); and females often select the depression along the upper side midrib of leaves (Powell and Common 1985). Egg masses vary from 4 to 150 eggs. Under laboratory conditions, the largest mass usually is deposited first, with successively smaller numbers per oviposition bout over several days (Dumbleton 1932, Powell and Common 1985). In the field, females on average deposit fewer eggs per oviposition event; Geier and Briese (1980) tallied 23–26 per mass over four seasons; and Wearing et al. (1991) recorded a mean of 35 (range 4–96). Larvae pass through five or six instars; they can overwinter, but development during cooler months is slower.

Like most Archipini, early instars feed on the undersides of leaves within a silk chamber. Late instars may fold individual leaves, create a nest of several leaves webbed together, or web leaves to fruit and feed on the surface of the fruit. Caterpillars on deciduous trees and shrubs feed as long as leaves remain on the host plant and then drop to the ground, where they may feed on understory vegetation or survive in leaf litter. Pupation occurs in the larval nest, and metamorphosis takes about 10 d at 20°C (Danthanarayana 1975).

Table 1. Documented host plants for *Epiphyas postvittana*

Genus/species	Family	Common name
Acacia sp.	Fabaceae	wattle
Acca sellowiana	Myrtaceae	horn of plenty
Actinidia chinensis	Actinidaceae	Chinese gooseberry
Actinidia deliciosa	Actinidiaceae	kiwifruit
Adiantum sp.	Pteridophyta	maidenhead fern
Alnus glutinosa	Betulaceae	black alder/European alder
Amaranthus sp.	Amaranthaceae	amaranth
Arbutus sp.	Ericaceae	madrone
Arctotheca calendula	Asteraceae	capeweed
Artemisia sp.	Asteraceae	sagebrush
Aquilegia sp.	Ranunculaceae	columbine
Astartea sp.	Myrtaceae	astartea
Aster sp.	Asteraceae	aster
Baccharis sp.	Asteraceae	baccharis
Billardiera sp.	Pittosporaceae	billardiera
Boronia sp.	Rutaceae	baronia
Brassica sp.	Brassicaceae	mustard
Breynia sp.	Euphorbiaceae	breynia
Bursaria sp.	Pittosporaceae	bursaria
Buddleja sp.	Loganiaceae	butterfly bush
Calendula sp.	Asteraceae	marigold
Callistemon sp.	Myrtaceae	bottlebrush
Camellia japonica	Theaceae	camellia
Campsis sp.	Bignoniaceae	trumpet-vine
Cassia sp.	Fabaceae	senna
Ceanothus sp.	Rhamnaceae	red-root/lilac
Centranthus spp.	Valerianaceae	fox-brush
Chenopodium album	Chenopodiaceae	fat-hen
Choisya sp.	Rutaceae	choisya
Chrysanthemum sp.	Asteraceae	chrysanthemum
Citrus spp.	Rutaceae	citrus
Clematis sp.	Ranunculaceae	virgin's-bower
Clerodendron sp.	Verbenaceae	glory-bower
Correa sp.	Rutaceae	correa
Cotoneaster sp.	Rosaceae	cotoneaster
Crataegus sp.	Rosaceae	hawthorn
Crocosmia sp.	Iridaceae	montbretia
Cupressus sp.	Cupressaceae	cypress
Cydonia sp.	Rosaceae	quince
Cytisus scoparius	Fabaceae	Scotch broom
Dahlia sp.	Asteraceae	dahlia
Datura sp.	Solanaceae	thorn-apple
Daucus sp.	Apiaceae	carrot
Diospyros kaki	Ebenaceae	Japanese persimmon
Diospyros sp.	Ebenaceae	malabar ebony
Dodonaea sp.	Sapindaceae	dodonaea
Eriobotrya sp.	Rosaceae	loquat
Eriostemon sp.	Rutaceae	eristemon
Escallonia sp.	Grossulariaceae	escallonia
Eucalyptus sp.	Myrtaceae	eucalyptus
Euonymus sp.	Celastraceae	euonymus
Forsythia sp.	Oleaceae	fosythia
Fortunella sp.	Rutaceae	kumquat
Fragaria sp.	Rosaceae	strawberry
Gelsemium sp.	Loganaceae	jasmine
Genista sp.	Fabaceae	broom
Gerbera sp.	Asteraceae	daisy
Grevillea sp.	Proteaceae	spider-flower
Hardenbergia sp.	Fabaceae	hardenbergia
Hebe spp.	Scrophulariaceae	hebe/speedwell
Hedera spp.	Araliaceae	ivy
Helichrysum sp.	Asteraceae	everlasting
Humulus lupulus	Cannabaceae	hops
Hypericum perforatum	Clusiaceae	St. John's wort
Jasminum spp.	Oleaceae	jasmine
Juglans sp.	Juglandaceae	walnut

Table 1. (continued on next page)

Table 1. *(continued)*

Genus/species	Family	Common name
Lathyrus sp.	Fabaceae	pea
Lavandula sp.	Lamiaceae	lavender
Leucadendron sp.	Proteaceae	leucodendron
Leptospermum sp.	Myrtaceae	manuka
Ligustrum spp.	Oleaceae	privet
Litchi chinensis	Sapindaceae	lychee
Lonicera sp.	Caprifoliaceae	honeysuckle
Lupinus sp.	Fabaceae	lupine
Lycopersicum sp.	Solanaceae	tomato
Macadamia sp.	Proteaceae	macadamia
Malus spp.	Rosaceae	apple
Mangifera sp.	Anacardiaceae	mango
Medicago sativa	Fabaceae	alfalfa
Melaleuca sp.	Myrtaceae	bottlebrush
Mentha sp.	Lamiaceae	mint
Mesembryanthemum sp.	Aizoaceae	ice-plant
Michelia sp.	Magnoliaceae	banana-shrub
Monotoca sp.	Ericaceae	monotoca
Myoporum sp.	Myoporaceae	sandle-wood
Oxalis sp.	Oxalidaceae	wood-sorrel
Parthenocissus sp.	Vitaceae	ivy
Pelargonium sp.	Geraniaceae	geranium/strok's-bill
Persea americana	Lauraceae	avocado
Persoonia sp.	Proteaceae	persoonia
Petroselinum sp.	Apiaceae	parsley
Philadelphus sp.	Hydrangeaceae	mock-orange
Photinia sp.	Rosaceae	photinia
Phyllanthus sp.	Euphorbiaceae	phyllanthus
Pittosporum sp.	Pittosporaceae	pittosporum
Pinus spp.	Pinaceae	pine
Plantago lanceolata	Plantaginaceae	plantain/ribwort
Platysace sp.	Araliaceae	platysace
Polygala sp.	Polygonaceae	milkwort
Polygonum sp.	Polygonaceae	knotweed
Populus spp.	Salicaceae	poplar and cottonwood
Populus nigra	Salicaceae	black poplar
Prunus armeniaca	Rosaceae	apricot
Prunus persica	Rosaceae	peach
Pteris sp.	Pteridophyta	brake-fern
Pulcaria sp.	Asteraceae	fleabane
Pyracantha sp.	Rosaceae	fire-thorn
Pyrus sp.	Rosaceae	pear
Quercus sp.	Fagaceae	oak
Ranunculus sp.	Ranunculaceae	buttercup
Raphanus sp.	Brassicaceae	raddish
Reseda sp.	Resedaceae	coneflower
Ribes sp.	Grossulariaceae	currant
Rosa sp.	Rosaceae	rose
Rubus spp.	Rosaceae	raspberry and boysenberry
Rumex crispus	Polgonaceae	curled dock
Rumex obtusifolius	Polygonaceae	broadleaf dock
Salix sp.	Salicaceae	willow
Salvia sp.	Lamiaceae	sage
Senecio sp.	Asteraceae	ragwort
Sida sp.	Malvaceae	side
Sisymbrium sp.	Brassicaceae	mustard
Smilax sp.	Smilacaceae	cat-brier
Solanum tuberosum	Solanaceae	potato
Tithonia sp.	Asteraceae	sunflower
Trema sp.	Ulmaceae	trema
Trifolium spp.	Fabaceae	clover
Triglochin sp.	Juncaginaceae	arrow grass
Ulex europaeus	Fabaceae	gorse
Urtica sp.	Urticaceae	nettle
Vaccinium sp.	Ericaceae	blueberry
Vicia faba	Fabaceae	broad bean
Viburnum sp.	Caprifoliaceae	arrow-wood
Vinca sp.	Apocynaceae	periwinkle
Vitis spp.	Vitaceae	grape

Morphology

Egg. Eggs of *E. postvittana* (Fig. 1), like those of most Archipini and Sparganothini, are flat and broadly oval. The eggs are regularly overlapped, shingle-like (imbricate), in rows or oval patches, without scaling or debris applied by the female; there is no colleterial secretion visible on the eggs or surrounding substrate (Powell and Common 1985, Wearing et al. 1991). When newly laid, the eggs are pale yellow to white and translucent; the embryos become visible as incubation proceeds. The chorion is reticulated, which separates eggs of this species from some, but not all, tortricids in North America (Peterson 1965).

Larva. Mature larvae range from 10 to 20 mm long and are generally yellowish green with paler subdorsal (SD), subventral (SV) and ventral lines. First instars are ~1.5 mm long with a dark head and light-colored body; succeeding instars have a darker body than fully grown larvae. The head, prothoracic shield, legs, and anal plate are pale brown, the genal dash is present or absent, and the prothoracic shield is only slightly darker than the rest of the integument. These structures lack contrasting darker markings that are characteristic of larvae in many archipine genera and other Tortricinae. All instars are darker dorsally, and the pinacula of later instars are slightly paler than the surrounding integument. Danthanarayana (1975) tallied head capsule (HC) widths for each instar.

Larval chaetotaxy of *E. postvittana* is typical of most Archipini with the small SD2 pinaculum fused to the anterior edge of the larger SD1 pinaculum on abdominal segments 1–7. LBAM larvae can be distinguished from other North American Archipini and Sparganothini studied by MacKay (1962) by the following combination of characters: adfrontal area sharply pointed; distance between AF2 and P1 approximately equal to the distance between P1 and P2 (Fig. 8); a horizontal line connecting the AF2 setae midway between P1 and P2; SD pinacula usually rounded (not posteriorly elongated) and

Figs. 1–6. Immature stages of *Epiphyas postvittana*. 1. Egg mass. 2. Pupa. 3. Larva on leaf surface. 4. Larvae in leaf shelter. 5. Larva and damage. 6. Close-up of larva.

SV group unisetose on T2 and T3; tarsal coloration pale; spiracles of A1–7 smaller than the SD1 pinaculum but larger than the SD1 setal base; distance between the D1 setae greater than the distance separating D1 from SD1 laterally on the rounded or very slightly tapered anal shield; V1 setae on abdominal segment 9 no farther apart than the V1 on abdominal segments 7 and 8; and anal fork well developed with 7–9 straight pointed teeth, not minutely bifurcated at their tip.

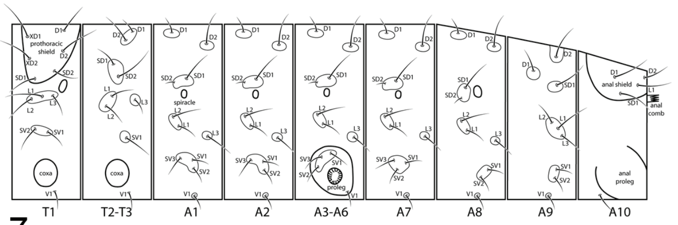
MacKay (1962) did not study mandibles, but LBAM usually has two "inner teeth" (sensu Passoa 1985) on the mandible (Fig. 9) in contrast to many common species in California that lack inner teeth or have a very large retinaculum. However, in some specimens of LBAM, the mandible has only one inner tooth or both teeth are worn smooth, leaving only a thin ridge. Finally, the P and MD setae on the head form a straight slanted line, and the D2 pinacula of A9 is shaped like an acute triangle (Dugdale et al. 2005).

Characters to separate LBAM from California species of Tortricidae were given by Gilligan and Epstein (2009). Eastern U.S. apple-feeding Tortricidae were illustrated by Chapman and Lienk (1971); only the larva of *Argyrotaenia velutinana* Walker is colored like LBAM, but the two species can be separated by using the above morphological characters.

Pupa. The pupa of *E. postvittana* (Fig. 2), like most tortricids, is greenish-brown initially and turns reddish-brown to dark brown when fully hardened. The average lengths of male and female pupae under laboratory conditions are 7.6 and 9.8 mm, respectively (Danthanarayana 1975). An illustration can be found in Zimmerman (1978; fig. 271, p. 460).

Using Adler's (1991) study of pupae of eastern U.S. apple-feeding Tortricidae, loss or reduction of the following characters is helpful for recognizing the pupa of *E. postvittana*: no vertex projections (present in many Tortricinae) and no dorsal abdominal pits (present in *Amorbia*, *Coelostathma*, and some introduced *Archips*). The vertex ("front" of Adler 1991) has two pairs of setae (some Archipini have only one pair), and the maxillae/labial palpi index is 2.4–2.7 in *E. postvittana*. The pupa of *E. postvittana* is most similar to that of *Pandemis,* but it differs in the relative length of the appendages; the prothoracic leg of *E. postvittana* extends past the prothoracic femur ("coxae" of Adler 1991) by more than half the height of the mesothoracic coxae. This distance is half the length of the mesothoracic coxae or less in *Pandemis.*

Adult. The forewing (FW) pattern of *E. postvittana* (Figs. 10–18) is sexually dimorphic and variable within each sex. The color varies from rust-brown to pale yellow with brown to dark brown markings. Males are more variable than females; although the basal half of the FW is slightly to markedly paler, the median fascia usually is well defined, and there is a dark mark on the costa distal to the median fascia. In California, the FW pattern includes a form with pale basal half and solid dark distal half (Fig. 15). The female FW color is more uniform, with a poorly defined median fascia and more speckled appearance than in males (Figs. 17–18). Not all phenotypes are illustrated here. Males have a FW costal fold, which is lacking in females, and this is an important diagnostic superficial feature in comparison with other tortricine moths in California. The fold extends from the base to ~0.3 the FW length and bears a flared scale fringe along its distal half. The strongly speckled underside, especially the hindwing, is diagnostic compared with that of *Argyrotaenia citrana* (Fernald) and other species that have similar, reduced FW pattern in the females. Most female *E. postvittana* have a dark mark on the dorsal margin



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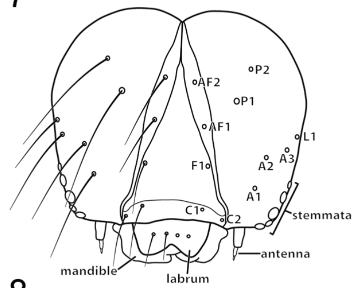

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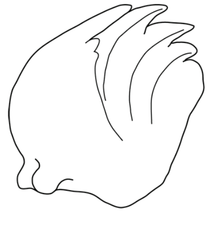

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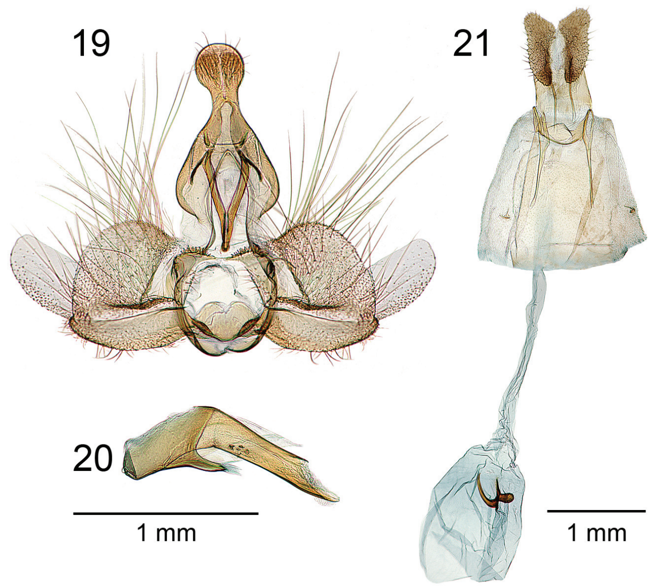
Figs. 7–9. Morphological features of the larva of *Epiphyas postvittana*. 7. Chaetotaxy, lateral aspect. 8. Head, anterior aspect. 9. Mandible.

of the forewing and two dark spots on the posterior of the thorax. The hindwing is variably mottled with dark speckles, especially the underside, usually more evident in females (Passoa et al. 2008). Forewing length ranges from 5.3 to 11.1 mm in males and 5.4 to 12.5 mm in females (Danthanarayana 1975). Several *Epiphyas* species in Australia resemble *E. postvittana*, which makes identification of specimens from that continent difficult (Bradley 1956). Male genitalia (Figs. 19–20) are distinctive, and examination of these structures is essential for reliable identification. Males have a combination of the following characters: spatulate (spoon-shaped) uncus; reduced socii; short valva with a broad sacculus; membranous lobe on the apex of the valve (the most diagnostic feature); and an aedeagus with 2–4 deciduous cornuti (Zimmerman 1978).

Female genitalia (Fig. 21) are typical of many Archipini, and females may be difficult to identify based on dissection alone. *E. postvittana* females have a combination of the following characters

Figs. 10–18. Adults of *Epiphyas postvittana*. 10–16. Males. 17–18. Females.



Figs. 19–21. Genitalia of *Epiphyas postvittana*. 19. Male, valva spread, aedeagus removed. 20. Aedeagus. 21. Female.

(Fig. 21): simple sterigma; long, straight ductus bursae which is 2/3 or more the length of the abdomen; and corpus bursae with a single, hook-shaped signum (Gilligan and Epstein 2009).

History of Previous Surveys for LBAM

The threat of LBAM to North American agriculture was recognized formally in 1957 when this species was included in the INKTO (Insects Not Known to Occur in the United States) pest alert series (Anonymous 1957). Although LBAM was excluded from a list of the top 100 most dangerous exotic pests of concern to the United States (McGregor 1973, unpublished[1]), most regulatory entomologists continued to cite LBAM in risk assessments. To help guide the U.S. exotic pest detection program in the late 1970s, a list of quarantine pests was compiled using economic and biological criteria. This study characterized LBAM as a pest of apples or pears (USDA/APHIS/PPQ 1976, unpublished[2]). A "high-hazard survey" was started in 1977 to sample areas of the United States that are prone to introductions of exotic insects, for example, near ports-of-entry (Wheeler and Hoebeke 2001). LBAM was recognized as a "high-hazard" target pest until the early 1980s (Bryce 1983, unpublished[3]) and continued to attract attention as a threat to crops (Lattin and Oman 1983) and agricultural trade (Holdeman 1986). The inclusion of LBAM in the PNKTO (Pests Not Known to Occur in the United States) series resulted in a written summary of the biology, distribution, and recognition of this pest (Whittle 1984). To provide more accurate survey information, two pathway studies on LBAM entering the United States were completed: Miller (1982, unpublished[4]) and Ford (1988, unpublished[5]).

The Cooperative Agricultural Pest Survey (CAPS) selected apple pests for one of their exotic surveys in the late 1980s. The survey guidelines recommended focusing on those states with high apple production and the proper climate to support LBAM if it were introduced (specifically California, Oregon, Virginia, North Carolina, South Carolina, Georgia) (OTIS 1985, unpublished[6]). Surveys continued sporadically from 1985 to 1995. By 1995, CAPS turned its attention to beetles and other wood borers, although a PRA (pest risk assessment) was completed on LBAM in 2003 (Venette et al. 2003). Since 1986, the results of LBAM surveys have been entered in the National Agricultural Pest Information System (NAPIS) database, either as positive or negative captures. These are summarized in Table 2 and Fig. 22.

In 2005, USDA/APHIS conducted a focused pheromone trap survey in parts of California (USDA/APHIS 2008) (Fig. 23), and these efforts failed to recover any moths recognized as LBAM (R. Dowell, CDFA, personal communication). Most areas where trapping was conducted were outside of the presently known range of LBAM in California (11 counties including Mendocino, Tulare, and San Diego); hence the negative results are not surprising. The San Francisco Bay Area counties of Alameda, Contra Costa, Napa, Solano, Marin, San Francisco, and San Mateo were not included in the survey. However, trapping was conducted in Santa Cruz and Santa Clara counties (USDA/APHIS 2008), where LBAM was widespread and abundant by 2007.

Table 2. Surveys for LBAM by Plant Protection Quarantine region (data from NAPIS).

Eastern Region	
Alabama	1987
Florida	2007
Georgia	2001, 2004
Kentucky	1989, 1990, 1991, 1992, 2003, 2004, 2005,
Massachusetts	2000
Michigan	2007
Minnesota	2005, 2006, 2007
New York	1987, 1988, 1990
North Carolina	1993, 1994, 1996, 2005, 2006
Pennsylvania	2007
Rhode Island	2004, 2005
South Carolina	1997
Tennessee	1989, 1990
Vermont	2004, 2005
Western Region	
California	2005
Colorado	1993, 2003, 2004, 2005, 2007
Idaho	1997, 2002, 2007
Iowa	2006
Missouri	1994, 2007
Montana	1987, 1988
Nebraska	1992, 1993, 1994,
Nevada	2005, 2007
New Mexico	2005, 2007
Oregon	1986, 1988, 1990, 1991, 1993, 1994, 2003, 2004, 2007
Texas	1989, 1991, 2007
Utah	1987, 2002, 2004
Washington	1986, 1989, 1991, 1992, 2004, 2005, 2006, 2007

[1]McGregor, R. C. 1973. The emigrant pests. USDA/APHIS/PPQ Task Force report to the Administrator, unpublished.

[2]USDA/APHIS/PPQ. 1976. Light brown apple moth. *In* Selected foreign pests and diseases of primary concern to mainland agriculture in the United States of America. [Unpublished USDA report without pagination].

[3]Bryce, B. 1983. National/International pest list [and photos]. USDA/APHIS/PPQ [unpublished report without pagination].

[4]Miller, C. E. 1982. *Epiphyas postvittana*. USDA/APHIS/PPQ unpublished report. 3 pp.

[5]Ford, E. J. 1988. *Epiphyas postvittana* pathway study. USDA/APHIS/PPQ unpublished report. 7 pp.

[6]OTIS Methods Development Center. 1985. Light brown apple moth, p. 28. *In* Exotic pest detection manual. USDA/APHIS/PPQ unpublished report. 51 pp.

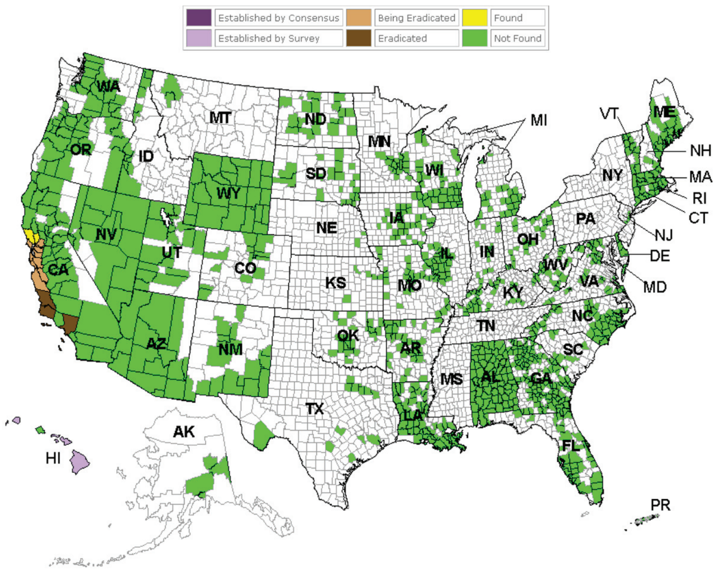


Fig. 22. Map of survey efforts for *Epiphyas postvittana* in the United States. Retrieved from the National Agricultural Pest Information System (NAPIS) at http://pest.ceris.purdue.edu.

The 2005 survey protocol was as follows. Traps were deployed May to October at a density of 1/mi^2. They were checked every 2 wk and relocated within the same square mile every 6–10 wk, up to four times in the season. Altogether, 860 traps were used to survey ~1,943 sites in California (R. Dowell, CDFA, personal communication). Specimens perceived as possible LBAM by local USDA lab personnel were referred to the Plant Pest Detection Center (PPDC) of CFDA in Sacramento. Database records at PPDC verify that numerous specimens were referred to PPDC from several southern California sites (e.g., Santa Barbara, Burbank, San Diego) and stations in the San Joaquin Valley (e.g., Bakersfield, Clovis, Fresno). These were recognized as nontarget species by M. Epstein. Their sources are areas where LBAM is not now known to be established.

No specimens, however, were received by PPDC from Santa Clara and Santa Cruz counties in 2005 (CDFA Database). If LBAM was present in 2005, it may have been overlooked because of the low trap density (1/mi^2) and/or low density populations; that is, if LBAM had been restricted to small, localized colonies, trappings may have failed to detect them. However, ~22 of the 2005 trapping quadrats were deployed in the area from the cities of Santa Cruz to Soquel, which had the greatest density of LBAM captures in 2007–2008.

General Lepidoptera Surveys in Central California

During recent decades, students and professional, avocational, and retired entomologists have worked to document species richness and larval foods of moths at several reserves and urban sites in central California. It was during one of these projects that LBAM was first recorded in California, and to dismiss these projects as inconsequential for documenting spatial and temporal changes in the local moth faunas would be deeply misguided. Several other alien moth species were first recognized in this part of California as a result of these inventories, including *Agonopterix alstroemeriana* (Clerck) (from Berkeley in 1983), *Crocidosema plebiana* Zeller and *Parapediasia teterrella* (Zincken) (from Berkeley in 1988), *Platyedra subcinerea* (Haworth) and *Pyrausta volupialis* (Grote) (from Berkeley in 1997), *Noctua pronuba* L. (from Inverness in 2001), *Holcocera maroccanella* Amsel (from Berkeley in 2002), and *Lineodes elcodes* (Dyar) (from Berkeley in 2005) (Powell and Passoa 1991; Powell 1992, 2002a, 2002b; Powell et al. 2002, 2004).

Evidence that LBAM was not resident in the San Francisco Bay area until recently is provided by surveys based on larval collections and rearing, which did not find LBAM: at San Bruno Mountain, adjacent to Daly City, where 160 species of microlepidoptera were reared in the 1980s (De Benedictis et al. 2009) and 12 species in 1998, based on >700 larval collections; at Brooks Island and the Richmond shoreline, where 94 species were reared from 193 collections in the mid-1990s; and at Albany Hill on the East Bay shore, where 56 species of microlepidoptera were reared in the late 1990s. Moreover, because LBAM is readily attracted to lights, continuous blacklight monitoring probably would have detected this species sooner if it had been established in the East Bay area for many years before 2006, especially in association with the 20-yr inventory at Berkeley and the 1-yr census (2003–2004) at the John Muir Historic site in Contra Costa Co. All five of these localities are within the LBAM range documented in 2007.

Below is a detailed description of 14 moth surveys conducted in central coastal California during 1961–2008 that failed to detect LBAM (Table 3).

1. Alameda Co., Albany Hill (Albany city open space): R. L. Langston and Powell surveyed this island of badly disturbed habitat situated within a highly urbanized area through 70 diurnal and crepuscular visits in 1995–1999. Much of the hill has eucalyptus groves with mostly weedy understory, but the north slope has live oak and hazelnut woods with many native plants (botanists have recorded

Fig. 23. Map of light brown apple moth trap locations for California in 2005 (USDA/APHIS/PPQ 2008).

Table 3. Summary of moth surveys in central coastal California.

County, Locality	Years (no. dates sampled)	No. species recorded (no. reared)	No. Tortricidae recorded
1. Alameda, Albany Hill	1995–1999 (70)	113 (56)	15
2. Alameda, Berkeley	1986–2008 (>6,000)	>500+ (20)	53
3. Contra Costa, Richmond	1992–1997 (47)	228 (94)	47
4. Contra Costa, Muir House	2003–2004 (33)	>180 (0)	14
5. Contra Costa, Walnut Creek	1961–1973 (1,300)	>500 (20)	39
6. Marin, Inverness Ridge	1994–2008 (405)	550 (140)	72
7. Monterey, Big Creek Reserve	1980–2008 (227)	>850 (380)	82
8. Monterey, Hastings Reserve	1997–2008 (38)	>305 (50)	27
9. Napa, Quail Ridge	1994–2007 (160)	524 (0)	37
10. San Benito, Pinnacles	2003–2008 (>240+)	500+ (0)	39
11. San Mateo, San Bruno Mtn.	1961–1974, 1980–1993 (>200)	>315+ (166)	35
12. Solano, Cold Canyon	1989–2008 (203)	598 (±50)	47
13. Yolo, NE Davis	1997–2008 (>1,300)	185 (0)	10
14. Yolo, NW Davis	1998–2008 (1,170)	255 (<10)	23

213 species of plants, 100 of which are natives). One hundred and forty-three species of Lepidoptera, including 78 of microlepidoptera, of which 56 were reared from larvae, were collected at this site.

2. Alameda Co., Berkeley (urban): Three sites were sampled more or less continuously for varying periods: Capistrano St. 1978–1984, by Powell; Yosemite Rd. 1984–2009, by Powell; and California St. 1996–1999, by F. Sperling. Sites 1 and 2 are in the northeast part of Berkeley; site 3 is ~3.25 airline km to the south. At site 1, sampling was primarily by incandescent light in a covered porch; at site 2, by porch light in 1984–1986, at continuous blacklight against a wall from 1986 to 2009, supplemented by an occasional blacklight trap and porch light; and at site 3 by a blacklight sheet hung on a second-story balcony.

3. Contra Costa Co., Richmond shoreline: Y.-F. Hsu and Powell carried out two inventories: (1) Richmond Field Station (RSF) (UC Department of Engineering), and adjacent shoreline (California State Park) 1992–1994, where they made 28 daytime visits and recorded ~80 moth species, 48 by leaf mines or larval rearing. This was a remnant coastal prairie, along with elements of coastal sage scrub, salt marsh, and disturbed, weedy habitat. (2) Brooks Island (East Bay Regional Park District) is in San Francisco Bay ~0.4 km off Point Potrero at its nearest distance. This is a 47-acre rocky ridge that has resisted takeover by Mediterranean annual grasses and retains a rich native flora. It has remained relatively unused because of ownership policies and surrounding mud flats that prevent boat access except at high tide. Nineteen daytime visits were made, February to June and September to November in 1993–1997, including 26 blacklight trap collections on 13 dates. In total, 228 species of moths were recorded; larvae or larval mines were known for 94 of them (41%), based on 193 collections.

4. Contra Costa Co., John Muir National Historic Site (National Park Service, NPS): Susan O'Neil and M. Plemons, aided by Paul Johnson and other NPS personnel, volunteers, and students from Dominican University, conducted a 1-yr inventory (2003–2004), primarily using blacklight trapping. They deployed two or three traps for 1 or 2–3 consecutive, rain-free nights during the new moon phase of each month for a total of 33 sampling dates; 83 collections were made at 26 sites that represented differing vegetation types. A few diurnal species were recorded during butterfly surveys, but no larval rearing was attempted.

5. Contra Costa Co., **Walnut Creek** (suburban): Powell conducted a year-round inventory of moths with light traps (blacklight and fluorescent "warm white" intermittently) regularly for 5 yr at a suburban site near the foot of Shell Ridge (1961–1966) and sporadically for >6 yr at a site above San Ramon Creek × Southern Pacific RR (1966–1973). Occasional diurnal visits and larval collections were made.

6. Marin Co., Inverness Ridge (suburban and Pt. Reyes National Seashore, NPS): Historical collections were made by W. Bauer, S. Buckett, C.Toschi, W. Patterson, Powell, and others between 1940 and1965 (see Powell 2005a for more data). Subsequent blacklight collections have been made by Powell and assistants: (1) 1994–2008, varying periods (2–34 continuous dates, total of 318 dates), primarily in May and September–October, at several sites in Inverness and Inverness Park (Powell 2005a); and (2) a 6-yr series of diurnal, larval, and blacklight trap samples, March through October, 1996–2000 and 2005–2006, along a transect of a 1995 wildfire (Powell 2005b). This survey included diurnal collections of adults (59 dates) and larvae (350 collections), as well as blacklight trap samples (68).

7. Monterey Co., Big Creek Reserve (UC Natural Lands Reserve, UCNLR): Powell, Y.-F. Hsu, B. Scaccia, and other students made a sporadic but comprehensive inventory of Lepidoptera, between 1980 and 2008, most intensively from 1986 to 1993. This included diurnal and nocturnal searches for larvae (>1,400 collections) and adults (blacklight sheet and trap collections), usually three samples at different elevations per night. The reserve spans sea level to 850 m elevation; and blacklight samples, although intermittent, were made in all months of the year and at all elevations, the fewest were above 700 m (15 samples) and during the winter (47 in November–February).

8. Monterey Co., Hastings Reservation (UCNLR): Animals and plants of this reserve, located in Upper Carmel Valley, have been studied since the 1930s. During 1938–1954, J., and D. Linsdale, B. Davis, and others collected moth at lights. Macro moths were emphasized, and this is the only extensive historical inventory of moths from the central Coast Range. In 1997, Powell and his students began additional sampling and reassessment of the historical material. During

1997–2008, 35 blacklight sheet and trap collections were made from March to October. Diurnal and larval collections were emphasized at this site (Powell 1999).

9. Napa Co., Quail Ridge Reserve (UCNLR): W. D. Patterson and G. Kareofelas surveyed this chaparral and gray pine woodland, adjacent to Lake Berryessa, from 1994 to 2007 during daytime and nocturnal visits, about half of which involved overnight sampling by blacklight and mercury vapor light. No larval collections were attempted. Tiny moths were neglected, so microlepidoptera are underrepresented, ~40% of the total species (207 including microlepidoptera and pyraloids); but larger micros, including all tortricids, were collected (W. Patterson, personal communication).

10. San Benito Co., Pinnacles National Monument (NPS): Paul Johnson led an intensive 1-yr inventory in 2003–2004, using blacklight traps and sheets (usually three per night) including sporadic diurnal, and incandescent light collections. He continued to monitor lights at the station through 2008 (P. Johnson, NPS, personal communication).

11. San Mateo Co., San Bruno Mountain (San Mateo Co. Park): C. D. MacNeill, Powell, P. A. Opler, and others made sporadic diurnal collections during 1961–1974. In 1980–1988, J. A. De Benedictis, D. L. Wagner, and J. W. Whitfield made a survey of microlepidoptera, primarily by diurnal collections of adults and larvae. Host plants of 160 small moths were reported, including records from MacNeill, Powell, and Opler, based on ~700 larval collections (De Benedictis et al. 1990). Visits spanned all months except December, but most sampling was done from February to June.

R. L. Langston collected all moths year-round between 1981 and 1993, primarily with diurnal collections and sampling lights on the buildings at the crest of the mountain. His representation of microlepidoptera was not comprehensive (48 spp.), but it included 35 tortricid species, of which 13 were previously unrecorded from this site. Powell made 17 larval collections in 1998 (March, April, July, August) and reared 12 species of microlepidoptera.

12. Solano Co., Stebbins Cold Canyon Reserve (UCNLR): J. A. De Benedictis, assisted by others, conducted a 20-yr inventory (1989–2008) at this reserve, which features relatively undisturbed oak woodland, chaparral, and riparian vegetation, in the Putah Creek drainage below Monticello Dam. Sporadic blacklight sampling has been done in all months, most commonly from March to October. Diurnal collecting has been emphasized (75 dates), including occasional larval rearing.

13. Yolo Co., Northeast Davis (suburban): G. Kareofelas carried out a backyard census of moths from 1997–2008. He used a blacklight sporadically year-round, supplemented by daytime observations, without larval rearing. All moths are recorded except tiny micros. The suburban yard features many native plants.

14. Yolo Co., Northwest Davis (suburban): J. A. De Benedictis conducted a survey by blacklight sheet in his urban backyard, primarily March–October, 1998–2008. There have been 93 daytime collections without larval rearing.

Discovery of LBAM in California

The first specimen to be recognized as *Epiphyas* in California was attracted to blacklight at Berkeley (Yosemite Rd.), California (site 2), on 19 July 2006, and the second on 19 November 2006. This site had been censused for all moth species for 20 yr. In 2006, the blacklight was monitored (by JAP) on ~140 dates through June, and 127 dates July–December.

Dr. Marianne Horak of the Australian National Collection, Canberra (CSIRO) confirmed identification of the original specimens as *Epiphyas postvittana* in late January 2007, and that information was relayed to CDFA and USDA, who initiated pheromone trap surveys in early February. Captures at Richmond, ~6 airline miles from the Berkeley site (survey site 2) within 1 wk confirmed that LBAM was established in the East Bay area, and captures in San Francisco soon thereafter revealed widespread establishment. Subsequently LBAM males were recorded at the Berkeley site on 5 dates in 2007 (July to September); on 15 dates in 2008 (21 specimens in April through mid-November); and in 2009, LBAM numbers increased dramatically, to >1,340 moths on 145 dates.

More than 257,000 individual specimens of adult LBAM were trapped using pheromone lures from 2007-2009 in 18 California counties. The following locations and dates are a chronological account and do not reflect colonization; they represent the continual discovery of the range of the species in Central California as more traps were deployed. The earliest CDFA collection dates were from Berkeley, Alameda Co. (27 February 2007) and Richmond, Contra Costa Co. (6 March 2007). Adult specimens of LBAM from pheromone traps were first received by one of the authors (MEE) in the Plant Pest Identification Laboratory, CDFA, on 9 March 2007. During the next 2 wk, additional specimens were identified from Albany (Alameda Co.) and El Cerrito (Contra Costa Co.). The first specimens from San Francisco Co. were extracted from traps in Golden Gate Park on 22 March, followed by samples from Sausalito and San Rafael (Marin Co.) on 27 March.

On 2 April the first samples of *E. postvittana* were found in Palo Alto (Santa Clara Co.) and on 13 April in Belmont (San Mateo Co.). The first specimens from Santa Cruz Co. (Soquel) were discovered in trap samples on 12 April, followed by many samples from the same general area, as well as Santa Cruz and Capitola during the remainder of the month. Also on 12 April, the first samples were found in Monterey Co. (at Prunedale), followed shortly by captures in Pajaro, Royal Oaks, and Seaside.

The first sample from Napa Co. came from the city of Napa on 9 May, followed by Solano Co. on 27 June from the city of Vallejo. A single LBAM was found in a trap in Los Angeles Co. (Sherman Oaks) on 28 June. San Luis Obispo Co. was the last new county reported in 2007 with a sample collected in Cambria on 25 September.

In 2008, LBAM was reported from three additional counties: Santa Barbara (Carpinteria) on 15 January, Sonoma (Sonoma) on 15 February, and San Benito (Aromas) on 17 April. In 2009, LBAM was documented from Ventura Co. in February, Yolo Co. in April, and San Joaquin Co. in June. LBAM was rediscovered in Los Angeles and San Luis Obispo Counties in July, 2009 after going undetected in 2008.

Summary and Conclusions

The potential introduction of LBAM into the United States has been a concern to USDA for decades (See Table 2 and Fig. 22 for negative results). Its presence would not only represent a new pest that could inflict considerable damage to ornamental plants and agricultural crops, but could result in quarantines that would adversely affect agricultural exports to trading partners. Hence, the discovery of LBAM in California in 2007 was met with swift and broad action to document its range and understand the scope of the problem.

The San Francisco Bay Area has been subject to fairly intensive survey efforts in the past, both focused LBAM pheromone trapping and general Lepidoptera inventories. Hence, if LBAM had been present, or at least widespread and/or abundant, in the region before about 2006, it probably would have been detected. Despite this, focused surveys using pheromone traps in 2007–2009 resulted in >257,000 individuals from 18 California counties: Alameda, Contra Costa, Los Angeles, Marin, Monterey, Napa, San Benito, San Francisco, San Joaquin, San Luis Obispo, San Mateo, Santa Barbara, Santa Clara, Santa Cruz, Solano, Sonoma, Ventura, and Yolo. Although the ultimate impact of LBAM in California is yet to be realized, this moth has not become established in the agriculturally important Central Valley; and armed with accurate information on its distribution, morphology, detection, and control, prospects for its management appear optimistic. This study documents the importance of local faunal surveys and suggests that positive and negative data should be used in combination to accurately determine where and when exotic species become established.

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