Mini Risk Assessment
False codling moth, *Thaumatotibia* (=*Cryptophlebia*) *leucotreta* (Meyrick)
[Lepidoptera: Tortricidae]

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Introduction

Thaumatotibia leucotreta is a significant pest of fruit trees and field crops in portions of Africa (CIE 1976, Zhang 1994). Until recently, this pest had been most commonly known as *Cryptophlebia leucotreta* (Komai 1999). A detailed description of the rationale for the name change is included in this document. For the sake of scientific accuracy, we refer to the false codling moth as *T. leucotreta* throughout this report. We hope the change does not cause confusion. To our knowledge the risks posed by this pest for US agriculture and native ecosystems have not been evaluated previously in a formal pest risk assessment.

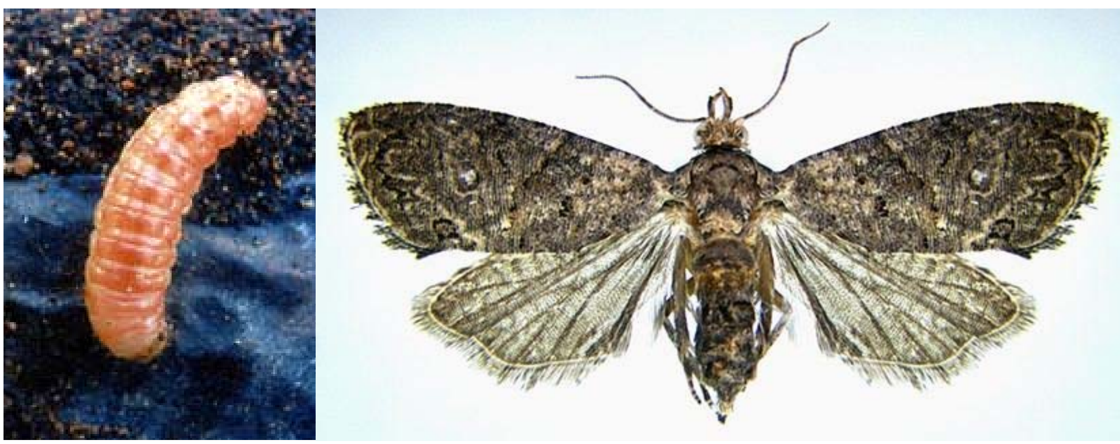

Figure 1. Larva and adult of *T. leucotreta*. Images not to scale.
[Larval image from http://www.arc.agric.za/institutes/ itsc/main/avocado/moth.htm; Adult image from Georg Goergen/IITA Insect Museum, Cotonou, Benin as published in (CAB 2000)]

1. **Ecological Suitability. Rating: Medium.** *Thaumatotibia leucotreta* is native to the Ethiopian zoogeographic province and presently occurs in much of Sub-Saharan Africa (CIE 1976, CAB 2000). Climates in the area occupied by this pest can be characterized as tropical, dry or temperate (CAB 2000). The currently reported global distribution of *T. leucotreta* suggests that the pest may be most closely associated with biomes that are generally classified as desert and xeric shrubland, tropical and subtropical grasslands, savannas, and shrubland; and tropical and subtropical moist broadleaf forest. Based on the distribution of climate zones in the US, we estimate that approximately 20% of the continental

US may be suitable for *T. leucotreta* (Fig. 2). See Appendix A for a more complete description of this analysis.

Our analysis is generally consistent with the speculation of Karvonen (1983) who suggested that this species was only likely to survive in "hot tropical or subtropical areas." The predicted absence of *T. leucotreta* from much of California concurs with Daiber (1989) who suggests that this pest may not perform well in Mediterranean climates, as found in portions of South Africa. The analysis differs somewhat from the suggestion that the pest may be able to establish in areas where the average annual low temperature is >-10°C (PPQ 1993).

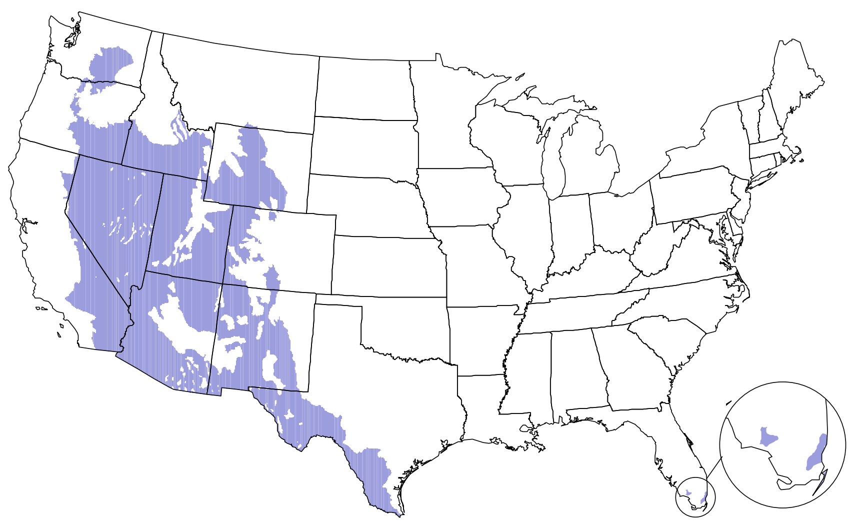

Figure 2. Predicted distribution of *Thaumatotibia leucotreta* in the continental US. Southern Florida is enlarged for detail.

2. **Host Specificity/Availability. Rating: Low/High.** False codling moth feeds on more than 70 host plants (CAB 2000), including: avocado (*Persea americana*), banana (*Musa paradisiaca*) bur weed (*Triumfeta* spp.), bean (*Phaseolus* spp.), bloubos (*Royena pallens*), boerboon (*Schotia afra*), buffalo thorn (*Zizyphus mucronata*), cacao (*Theobroma cacao*), carambola (*Averrhoa carambola*), castorbean (*Ricinus communis*), chayote (*Sechium edule*), citrus (*Citrus sinensis*, *Citrus* spp.), coffee (*Coffea arabica*, *Coffea spp*.), cola (*Cola nitida*), corn (*Zea mays*), cotton (*Gossypium hirsutum*, *Gossypium* spp.), cowpea (*Vigna unguiculata*, *Vigna* spp.), custard apple (*Annona reticulata*), elephant grass (*Pennisetum purpureum*), English walnut (*Juglans regia*), grape (*Vitis* spp.), guava (*Psidium guajava*), governor's plum (*Flacourtia indica*), Indian mallow (*Abutilon hybridum*), jakkalsbessie (*Diospyros mespiliformis*), jujube (*Zizyphus jujuba*), jute (*Abutilon* spp.), kaffir plum (*Harpephyllum caffum*), kapok/copal (*Ceiba pentranda*), khat (*Catha edulis*), kudu-berry (*Pseudolachnostylis maprouneifolia*), lima bean (*Phaseolus lunatus*), litchi (*Litchi chinensis*), loquat (*Eriobotrya japonica*), macadamia nut (*Macadamia ternifolia*), mallow (*Hibiscus* spp.), mango (*Mangifera indica*), mangosteen (*Garcinia mangostana*), marula

(*Sclerocarya caffra, S.birrea*), monkey pod (*Cassia petersiana*), oak (*Quercus* spp.), okra (*Ablemoschus esculentus*), olive (*Olea europaea* subsp. *europaea*), peach (*Prunus persica*), peacock flower (*Caesalpinia pulcherrima*), pepper/pimento (*Capsicum* spp.), persimmon (*Diospyros* spp.), plum (*Prunus* spp.), pineapple (*Ananas comosus*), pomegranate (*Punica granatum*), Pride of De Kaap (*Bauhinia galpini*), raasblaar (*Combretum zeyheri*), red milkweed (*Mumisops zeyheri*), rooibos/bushwillow (*Combretum apiculatum*), sida (*Sida* spp.), snot apple (*Azanza garckeana*), stamvrugte (*Chrysophyllum palismontatum*), sodom apple (*Calotropis procera*), sorghum (*Sorghum* spp.), soursop (*Annona muricata*), stemfruit (*Englerophytum magaliesmontanum*), Surinam cherry (*Eugenia uniflora*), suurpruim/large sour plum (*Ximenia caffra*), tea (*Camellia sinensis*), water-bessie (*Syzygium cordatum*), wig-'n-bietjie (*Capparis tomentosa*), wild fig (*Ficus capensis*), wild medlar (*Vangueria infausta*), wing bean (*Xeroderris stuhlmannii*), and yellow-wood berries (*Podocarpus falcatus*) (Del Valle and March 1972, Reed 1974, Schwartz and Kok 1976, Daiber 1980, Bourdouxhe 1982, Anon. 1983, USDA 1984, Javai 1986, La Croix and Thindwa 1986b, Daiber 1989, Newton 1989a, b, Silvie 1993, Zhang 1994, Sétamou et al. 1995, CAB 2003).

See Appendix B for a description of where host plants are grown commercially in the continental US.

3. **Survey Methodology. Rating: Medium**. Visual inspections of plant materials may be used to detect eggs, larvae, and adults of *T. leucotreta* (USDA 1984). Eggs will commonly be found on fruits, foliage, and occasionally on branches (USDA 1984). On citrus fruits and other fleshy hosts, dissections are needed to detect larvae; larvae are likely to be found in the pulp (USDA 1984). Infested fruits may be on or off the tree. In cotton, older larvae may be found in open bolls and cotton seed (USDA 1984). Occasionally adults may be observed on the trunk and leaves of trees in infested orchards (USDA 1984). For field crops such as corn, the whole plant is the recommended sample unit (Schulthess et al. 1991). Because larvae of *T. leucotreta* have a strongly aggregated spatial distribution among corn plants, a large sample size (>60 plants) is recommended (Schulthess et al. 1991, Ndemah et al. 2001b); however at low densities of the pest (<1 larva/plant) sample sizes may be prohibitively large to detect the pest (Schulthess et al. 1991).

   Robinson black light traps are ineffective at attracting adult *T. leucotreta* (Begemann and Schoeman 1999). Therefore, black light traps should not be used. This recommendation stands in stark contrast to the experience of Reed (1974) who used Robinson black light traps to monitor adult *T. leucotreta* in cotton for nearly 4 years. The effectiveness of black light traps may be improved if used in conjunction with pheromone lures (Möhr 1973). Mohr (1973) speculates that pheromone may provide a long-distant attractant, but that attraction to black light becomes much stronger when moths are in close proximity to light traps.

Sex pheromones have been identified, and the synthetic conpounds are highly attractive to males of *T. leucotreta*. Males are attracted to a two component blend of (*E*)-8-dodecenyl acetate and (*Z*)-8-dodecenyl acetate (Persoons et al. 1976, 1977, Newton et al. 1993). These components are most effective when used in a ratio between 70:30 and 30:70 (*E*:*Z*) (Persoons et al. 1976, 1977, Angelini 1979, Angelini et al. 1981, Bourdouxhe 1982). More recently, Newton et al. (1993) refined the sex pheromone and reported that a 90:10 ratio was optimal. A loading rate between 0.5 and 1.0 mg per septum was found to attract the greatest number of males (Jactel and Vaissayre 1988). The pheromone blend (1 mg applied to a rubber septum) has been used effectively with Pherocon 1C traps to capture male *T. leucotreta* (Newton et al. 1993). Delta traps have also been used (Newton 1988b, 1989b, Newton and Mastro 1989, La Croix 1990), but these have performed less well than either the Hoechst Biotrap or Pherocon 1C traps (Newton and Mastro 1989, Ochou 1993). Traps using closed polyethylene vials to dispense pheromones captured more moths than traps using rubber septa (using a 50:50 blend of (E)- and (Z)-8-dodecenyl acetate La Croix et al. 1985). Lures should be replaced every 2-4 weeks (Daiber 1978, Jactel and Vaissayre 1988)

Traps should be placed approximately 5 ft (1.5m) high (Blomefield 1989, Newton and Mastro 1989, Newton et al. 1993). Lures should be replaced every 8 wks (PPQ 1993). For routine monitoring, 1-2 traps per acre (2-5 traps/ha) is recommended (http://www.insectscience.co.za/phertraps.htm). Pheromone traps (homemade design with unspecified pheromone blend) have been used to monitor the number of *T. leucotreta* adult males in citrus orchards (Daiber 1978) and detect the presence of the pest in peach orchards (Daiber 1981).

Lures for *T. leucotreta* should not be used in the same trap with lures for the pink bollworm (*Pectinophora gossypiella*) because the combination of lures results in fewer pink bollworm captures (Schwalbe and Mastro 1988). Lures for *T. lecutreta* can be used in the same trap with lures for *P. scutigera* (Schwalbe and Mastro 1988).

Pheromone lures with (*E*)- and (*Z*)-8-dodecenyl acetate may also attract *Cydia cupressana* (native), *Hyperstrotia* spp. (PPQ 1993), *Cydia atlantica* (exotic) (Chambon and Frerot 1985), *Cydia phaulomorpha* (exotic) and *Cryptophlebia peltastica* (exotic) (Bourdouxhe 1982, Newton et al. 1993).

In citrus, attempts to disrupt mating in *T. leucotreta* with the two-component pheromone blend successfully disoriented males but failed to reduce damage caused by larvae (Hofmeyr et al. 1991).

4. **Taxonomic Recognition**. **Rating: Low.** *Thaumatotibia leucotreta* can be confused with many *Cydia* spp. including *C. pomonella* (codling moth) because of similar appearance and damage, however, unlike codling moth its host range does not include apples, pears or quince (USDA 1984). "In West Africa, *T. leucotreta* is often found in conjunction with *Mussidia nigrevenella*," however

they can be distinguished by close examination of morphological characters (CAB 2000). In South Africa, there is also an overlapping host range for *T. leucotreta* and *Cydia peltastica*, particularly on litchi and macadamia (Newton and Crause 1990).

For a more through description of the taxonomy and morphology of *T. leucotreta*, see Appendix C.

5. **Entry Potential. Rating: Medium.** Since 1984, 1,523 interceptions of *C. leucotreta* or "*Cryptophlebia* sp." [taxonomy consistent with nomenclature in PIN-309 database] have been reported (USDA 2003). Annually, approximately 82 (±7 standard error of the mean) interceptions of *C. leucotreta* or "*Cryptophlebia* sp." have been reported (USDA 2003). These interceptions are largely associated with international airline passengers (97%). The pest has been intercepted at 34 ports of entry in the United States. Most interceptions were reported from JFK International Airport (33%), Boston (9%), Dallas (9%), Atlanta (7%), Los Angeles (7%), Detroit (5%), Dulles airport (5%), and Des Plaines (5%). These ports are the first points of entry for cargo or airline passengers coming into the US and do not necessarily represent the intended final destination of infested material. Movement of potentially infested material is more fully characterized later in this document. *Cryptophlebia leucotreta* or "*Cryptophlebia* sp." were intercepted in association with 99 plant taxa (USDA 2003).

   Fumigation with ethylene dibromide (2 hrs @ 16 mg/L) combined with a cold treatment (21 days at 51°F [11C]) can control *T. leucotreta* in infested citrus (Schwartz and Kok 1976). Cold treatments of 31°F (-0.5C) for 24 days are effective at eliminating pupae (Myburgh and Bass 1969).

6. **Destination of Infested Material. Rating: High.**. When an actionable pest is intercepted, officers ask for the intended final destination of the conveyance. Material infested with *C. leucotreta* or "*Cryptophlebia* sp." (either carried by mail or international airline passengers) was destined for 39 states (including the District of Columbia USDA 2003). The most commonly reported destinations were New York (29%), Texas (13%), Massachusetts (9%), California (9%), Illinois (7%), Georgia (5%), Michigan (4%), Maryland (3%), Washington, DC (3%), and Minnesota (3%). Of these states, only Texas and California are likely to have a climate that would support populations of the pest.

7. **Potential Economic Impact. Rating: High.** *Thaumatotibia leucotreta* is a pest of economic importance to several crops, including: corn, cotton, citrus, litchi, macadamia, peach and plum, throughout sub-Saharan Africa, South Africa, and the islands of the Atlantic and Indian Oceans (Schwartz and Kok 1976, Daiber 1979, 1980, La Croix and Thindwa 1986a, b, Wysoki 1986, Blomefield 1989, Newton 1989b, Newton and Crause 1990, Silvie 1993, Sétamou et al. 1995). Larval feeding and development can affect fruit development at any stage,

causing premature ripening and fruit drop (Schwartz and Kok 1976, USDA 1984, Newton 1988a, 1989a, Begemann and Schoeman 1999). Damage to corn is caused from larvae entering the ear from the husk through the silk channel (Ndemah et al. 2001a).

All stages of citrus and stone fruits are vulnerable to attack (Newton 1988a). *Thaumatotibia leucotreta* larvae are capable of developing in hard green fruit before control measures can be started (Catling and Aschenborn 1974). Once a fruit is damaged, it becomes vulnerable to fungal organisms and scavengers (Newton 1989a). In peaches, up to 28% loss of late-peach crops has been reported (CAB 2003). Larvae damage stone fruits as they burrow into the fruit at the stem end and begin to feed around the stone (Blomefield 1978). Infestation can be identified by the brown spots and dark brown frass (Blomefield 1978). Peaches become susceptible to damage about 6 weeks before harvest (Daiber 1975). Detecting infested peaches can be difficult if fruit is still firm and abscission has not occurred; consequently, the danger of selling potentially infested fruit poses a serious threat to the peach industry (USDA 1984). On oranges, *T. leucotreta* caused 2-5% damage on Valencia and Navel oranges in 1954 (USDA 1984), but yield losses have been as great as 10-20% (CAB 2003). An infested orange shows brown, sunken spots with larval holes bored in the center of the spot (Bradley et al. 1979).

Thaumatotibia leucotreta has caused significant yield losses (≥30%) to macadamia crops in Israel and South Africa (La Croix and Thindwa 1986a, Wysoki 1986). Damage to macadamia nuts is caused from larvae feeding on the developing kernel after they pierce the husk and shell (La Croix and Thindwa 1986a). Nuts reaching 14 – 19 mm diameter size are at the most risk because nutrient content is the highest; concurrently, *T. leucotreta* reaches the adult stage by this point and is able to oviposit on these nuts (La Croix and Thindwa 1986a).

In Ugandan cotton, *T. leucotreta* caused 20% loss of early sown varieties and 42 - 90% loss of late varieties (Byaruhanga 1977). Larval penetration of cotton bolls facilitates entry of other microorganisms that can rot and destroy the boll (Couilloud 1994).

8. **Establishment Potential. Rating: Medium.** No wild infestations of *T. leucotreta* have been reported in the US. The apparently moderate rate of arrival combined with the potentially limited availability of suitable climate lowers the likelihood of establishment. However because this pest has a broad host range and suitable host plants are both common and abundant, a relatively high probability of pest establishment exists if the pest were introduced into a suitable climate. Should this pest become established in the US, the economic consequences are likely to be severe. Thus, the overall degree of risk posed by this pest is high, and vigilance is warranted.

   See Appendix D for a more detailed description of the biology of *T. leucotreta*.

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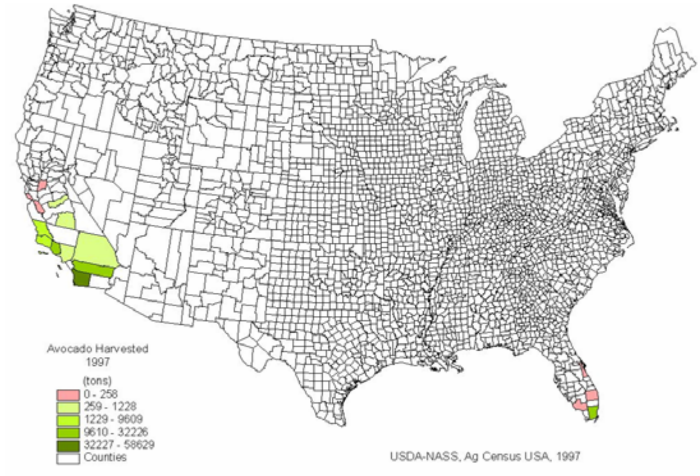
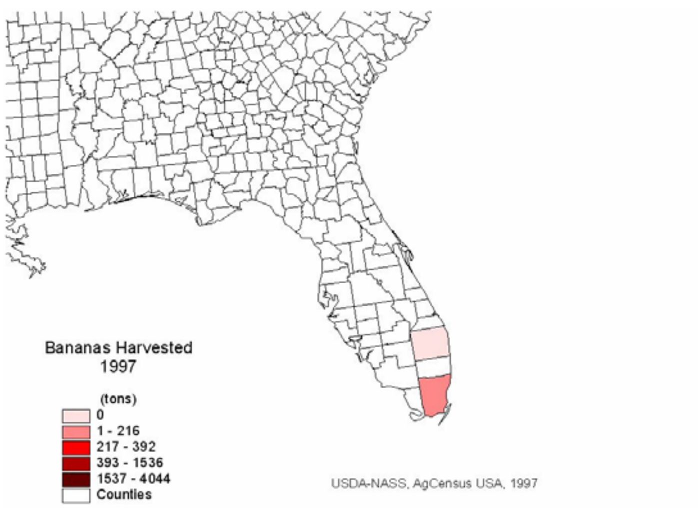
Appendix A. Comparison of climate zones. To determine the potential distribution of a quarantine pest in the US, we first collected information about the worldwide geographic distribution of the species (CAB 2000). We then identified which biomes (i.e., habitat types), as defined by the World Wildlife Fund (Olson et al. 2001), occurred within each country or municipality reported for the distribution of the species. Biomes were identified using a geographic information system (e.g., ArcView 3.2). An Excel spreadsheet summarizing the occurrence of biomes in each nation or municipality was prepared. The list was sorted based on the total number of biomes that occurred in each country/municipality. The list was then analyzed to determine the minimum number of biomes that could account for the reported worldwide distribution of the species. Biomes that occurred in countries/municipalities with only one biome were first selected. We then examined each country/municipality with multiple biomes to determine if at least one of its biomes had been selected. If not, an additional biome was selected that occurred in the greatest number of countries or municipalities that had not yet been accounted for. In the event of a tie, the biome that was reported more frequently from the entire species' distribution was selected. The process of selecting additional biomes continued until at least one biome was selected for each country. The set of selected biomes was compared to the occurrence of those biomes in the US.

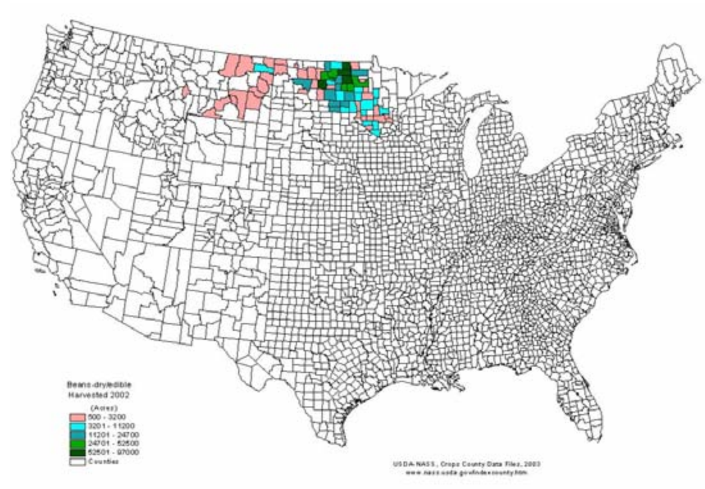
Appendix B. Commercial production of hosts of *Thaumatotibia leucotreta* in the continental US.



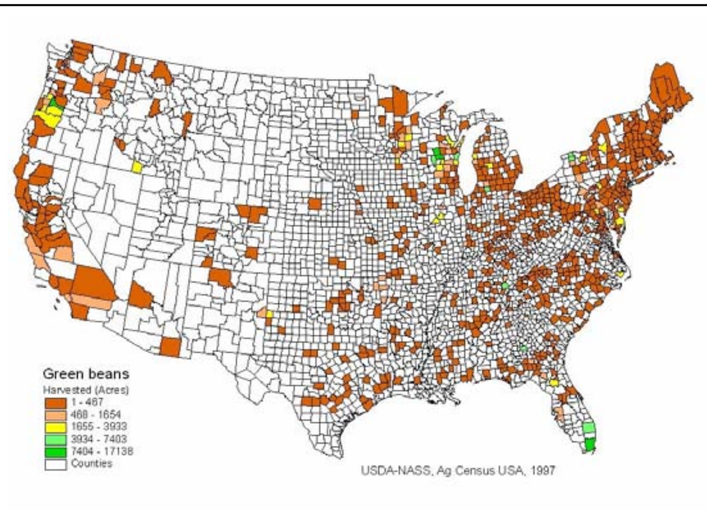
Map 1. Avocado (*Persea americana*)



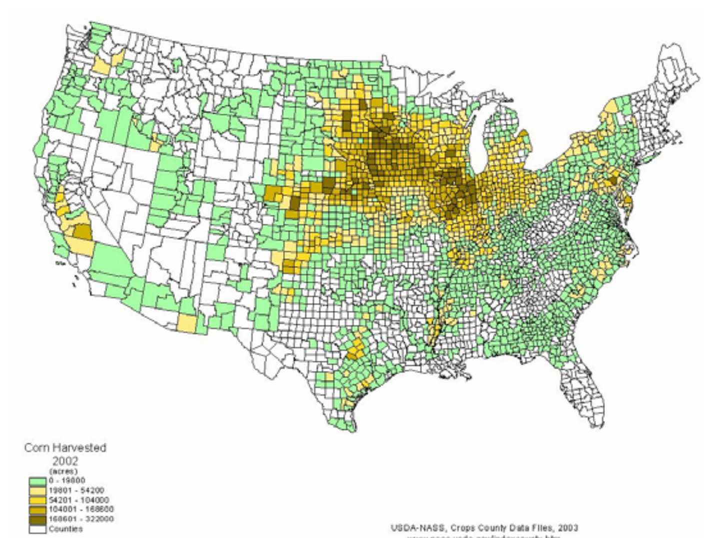
Map 2. Banana (*Musa paradisiaca*)



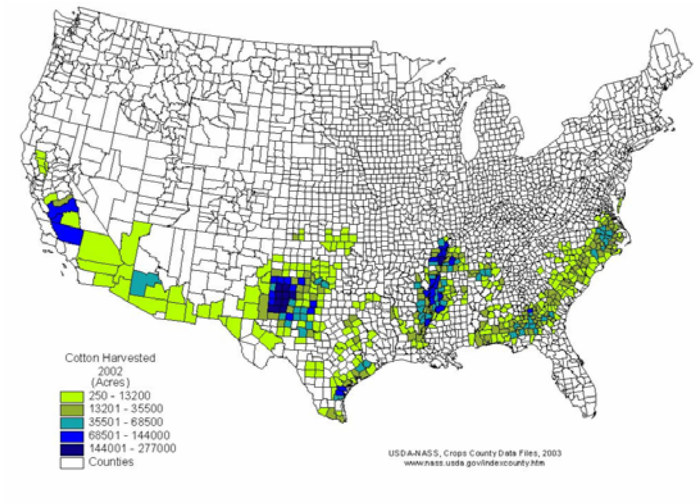
Map 3. Bean; dry, edible (*Phaseolus vulgais*)



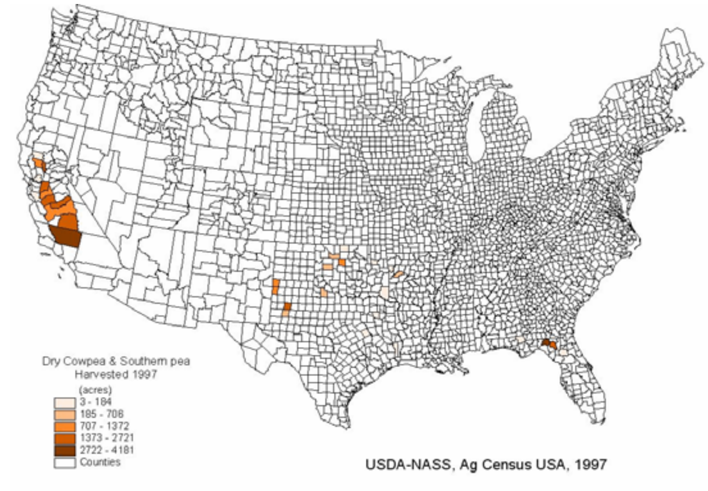
Map 4. Bean; green (*Phaseolus vulgaris*)



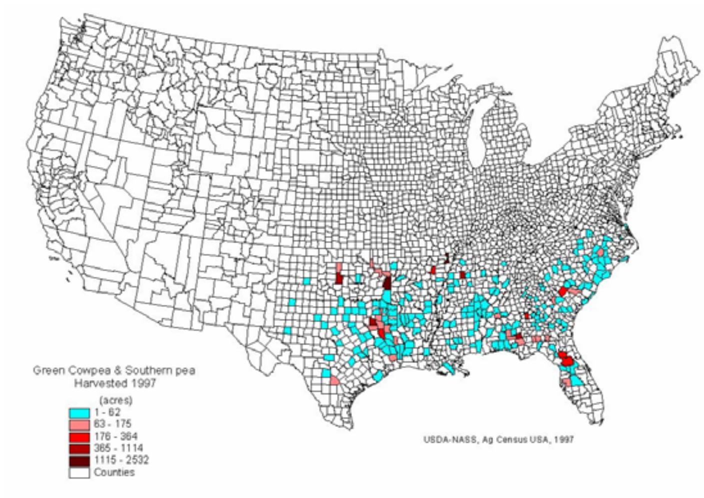
Map 5. Corn (*Zea mays*)



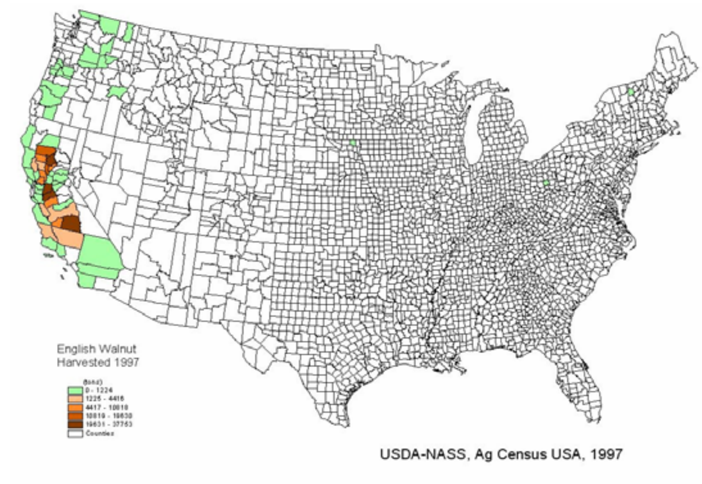
Map 6. Cotton (*Gossypium hirsutum*)



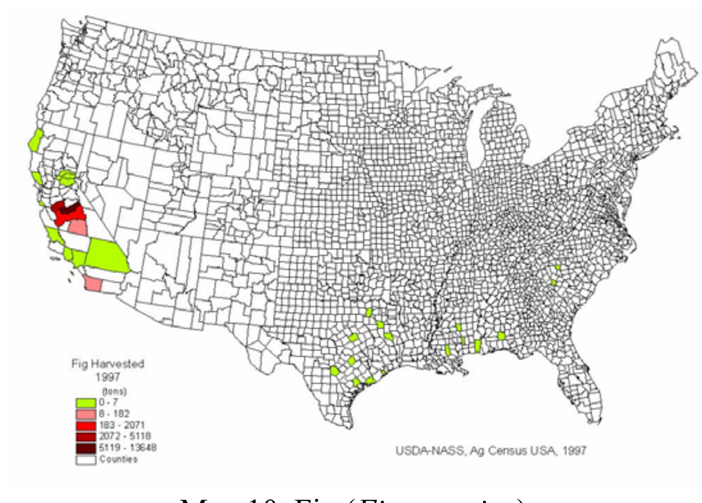
Map 7. Cowpea; dry (*Vigna unguiculata*)



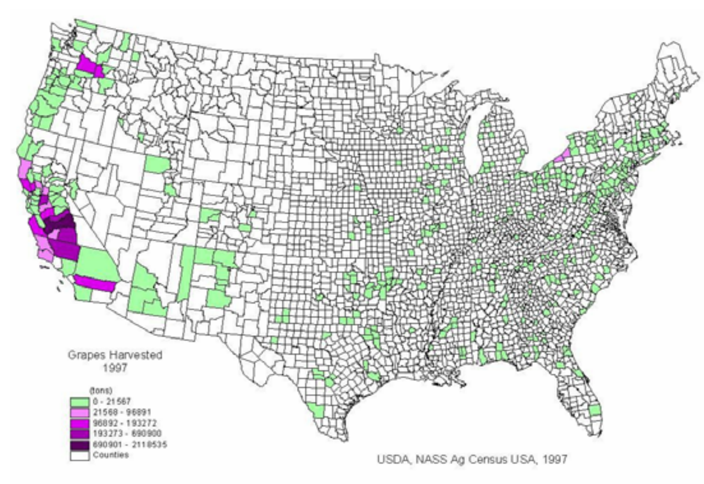
Map 8. Cowpea; green (*Vigna unguiculata*)



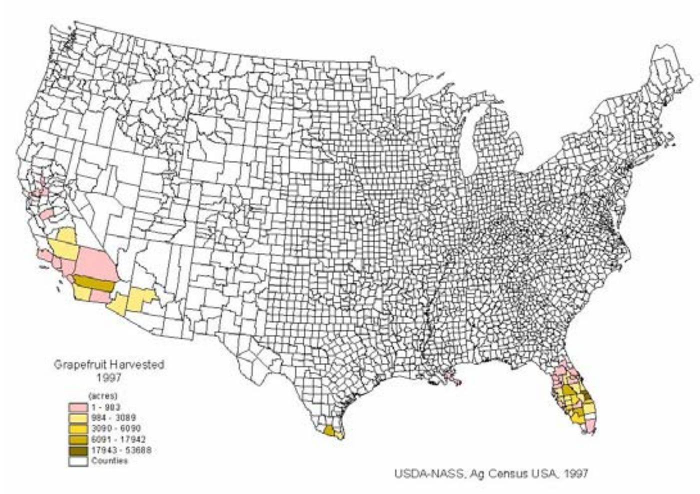
Map 9. English walnut (*Juglans regia*)



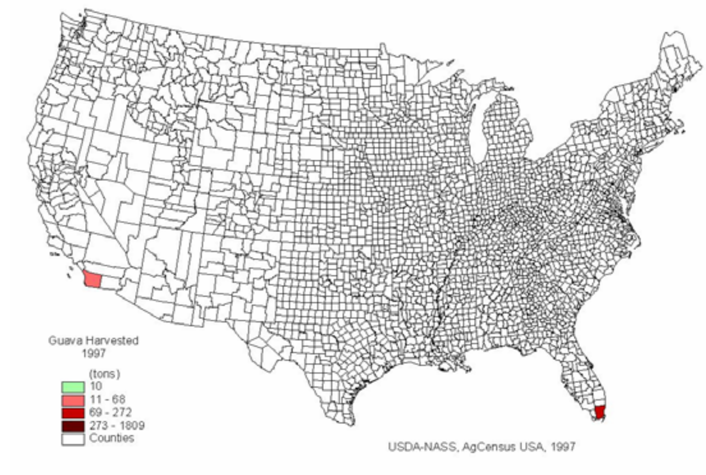
Map 10. Fig (*Ficus carica*)



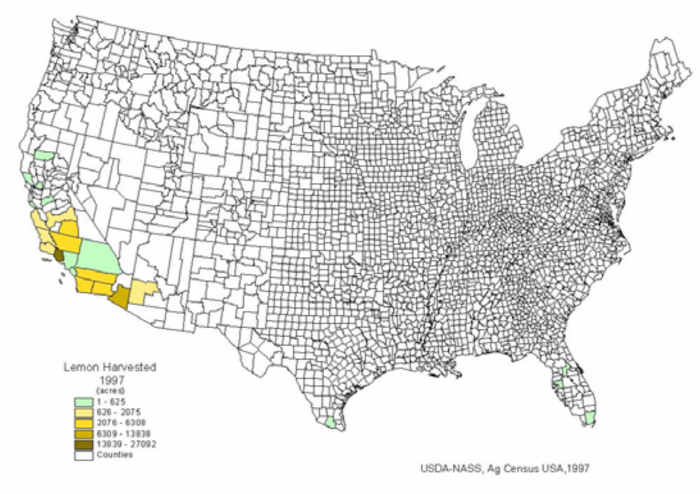
Map 11. Grape (*Vitis* spp.)



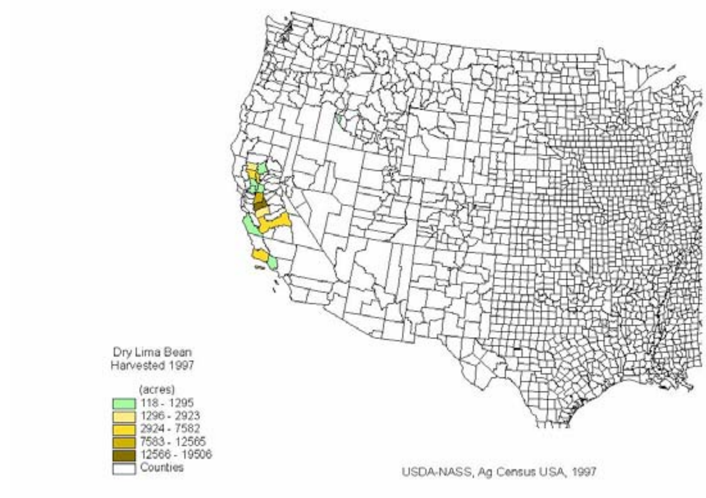
Map 12. Grapefruit (*Citrus paradisi*)



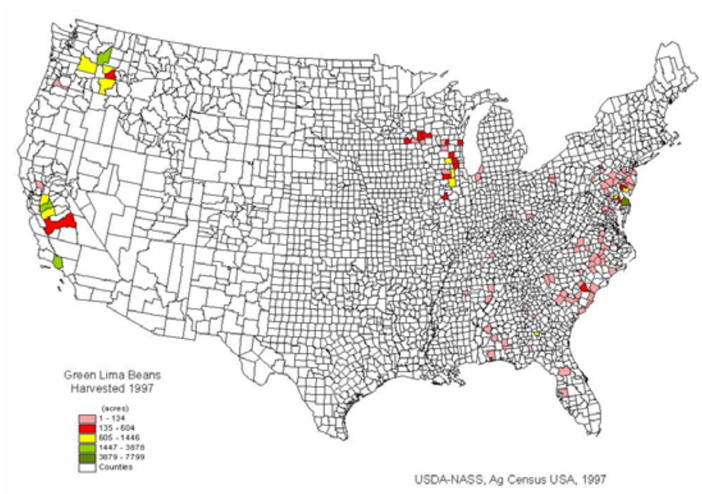
Map 13. Guava (*Psidium guajava*)



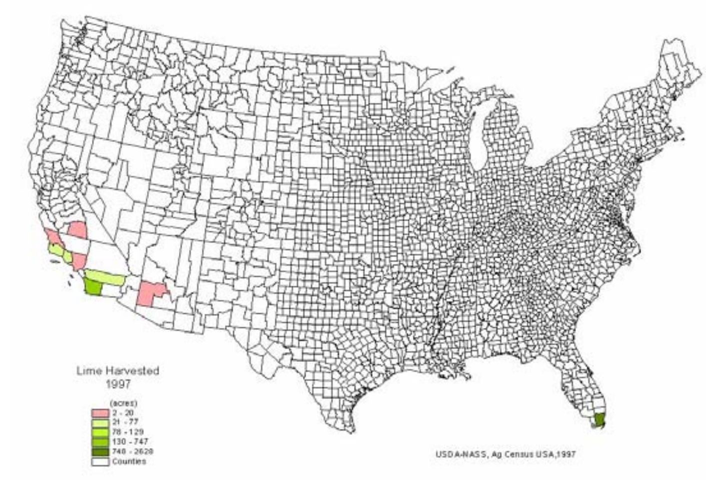
Map 14. Lemon (*Citrus limon*)



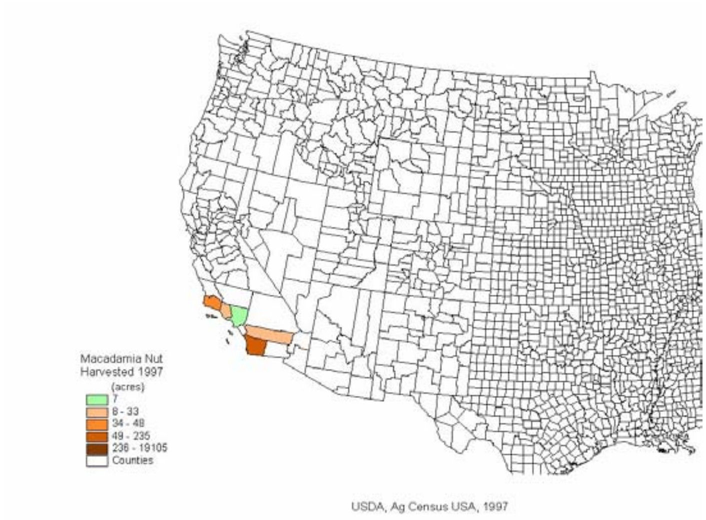
Map 15. Lima bean; dry (*Phaseolus limensis*)



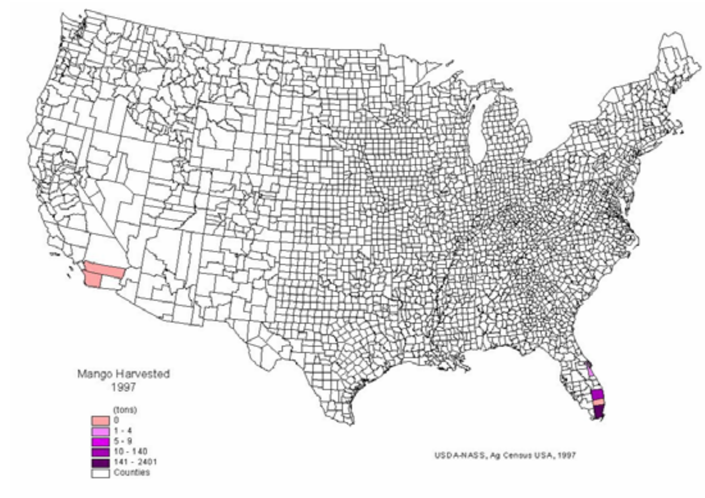
Map 16. Lima Bean; green (*Phaseolus limensis*)



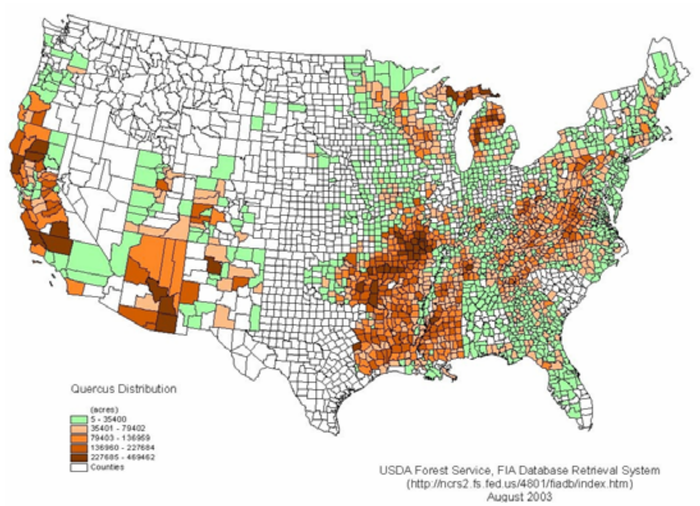
Map 17. Lime (*Citrus aurantifolia*)



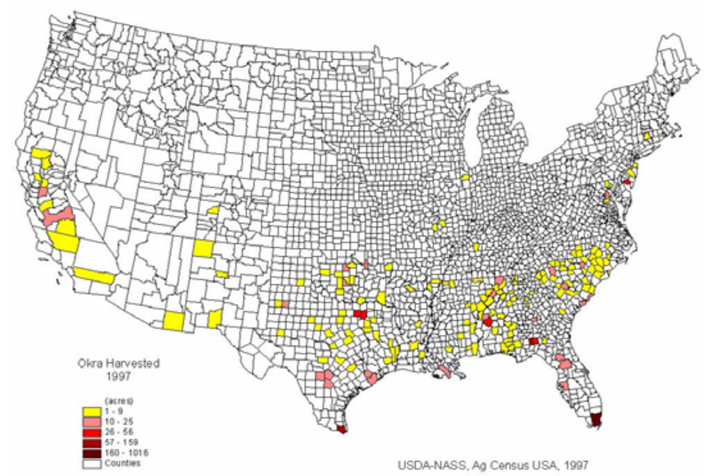
Map 18. Macadamia nut (*Macadamia ternifolia*)



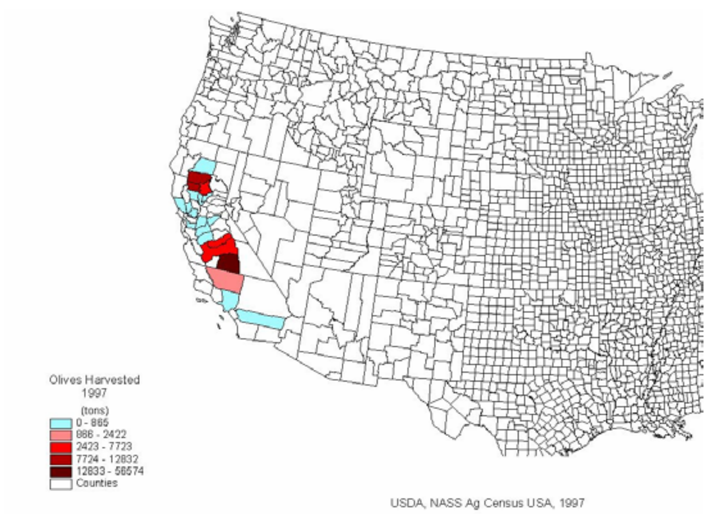
Map 19. Mango (*Mangifera indica*)



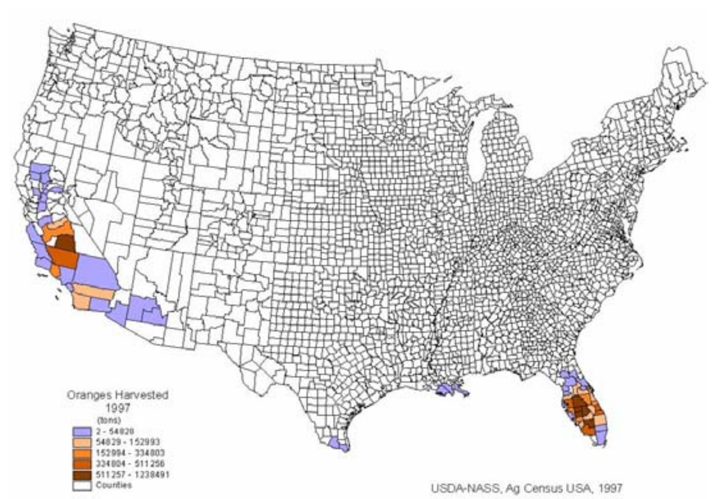
Map 20. Oak (*Quercus* spp.)



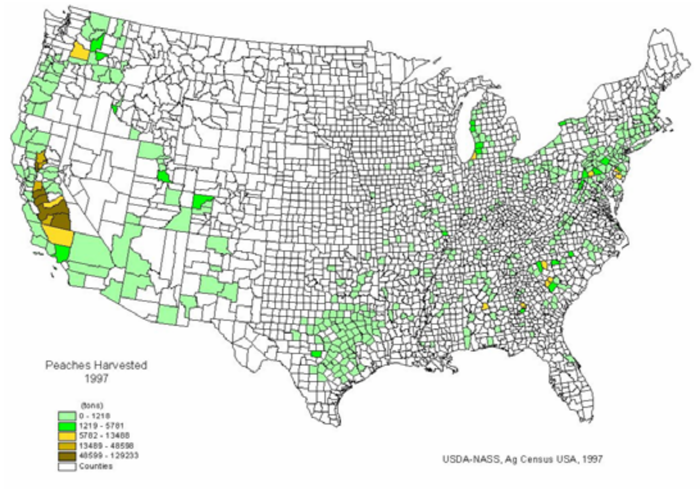
Map 21. Okra (*Abelmoschus esculentus*)



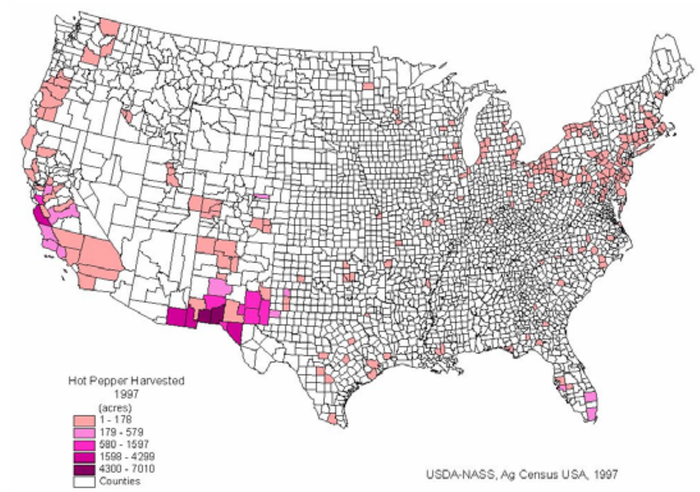
Map 22. Olive (*Canarium* spp.)



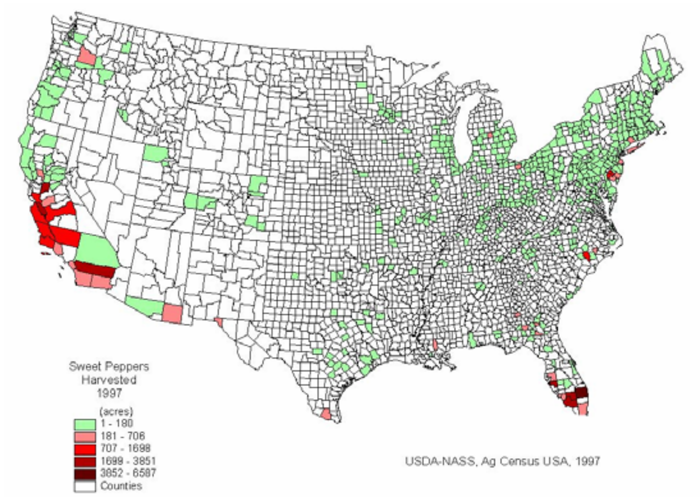
Map 23. Orange (*Citrus* spp.)



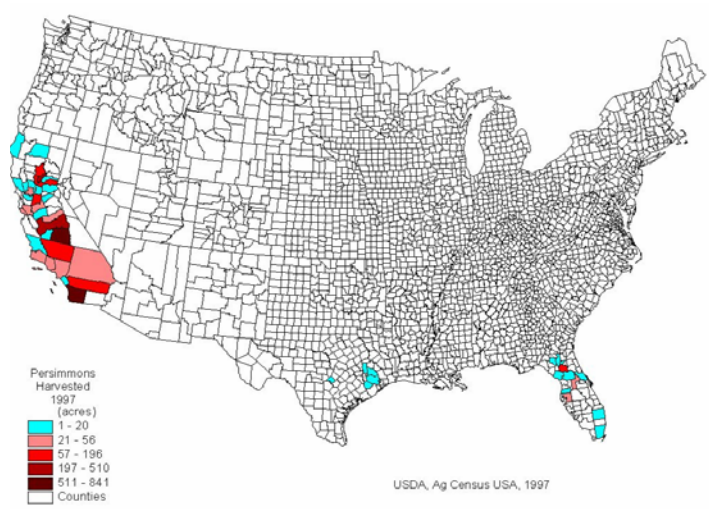
Map 24. Peach (*Prunus persica*)



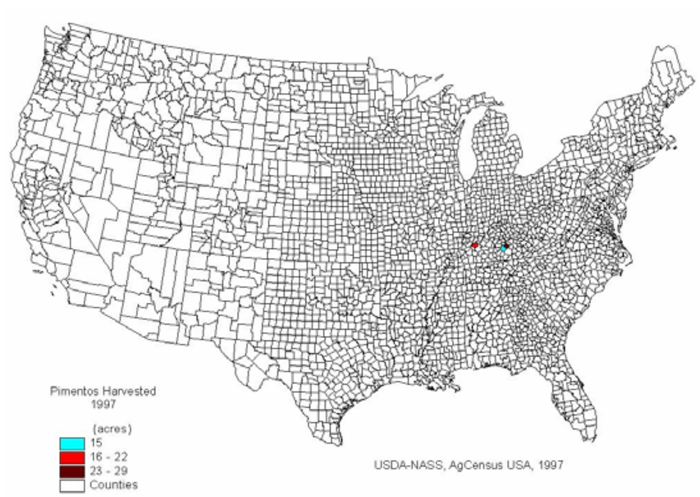
Map 25. Pepper; hot (*Capsicum* spp.)



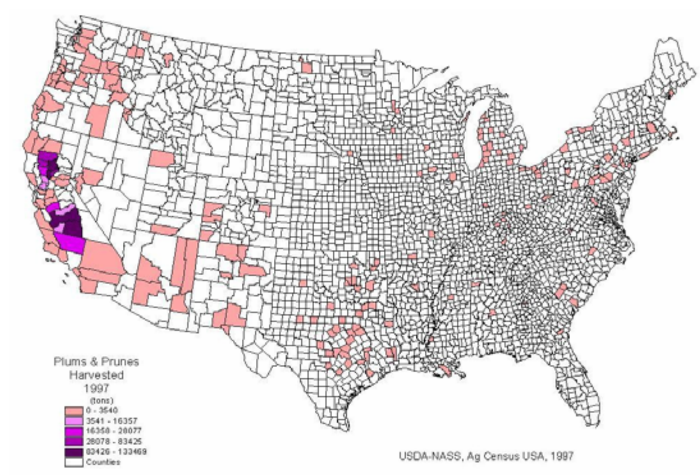
Map 26. Pepper; sweet (*Capsicum* spp.)



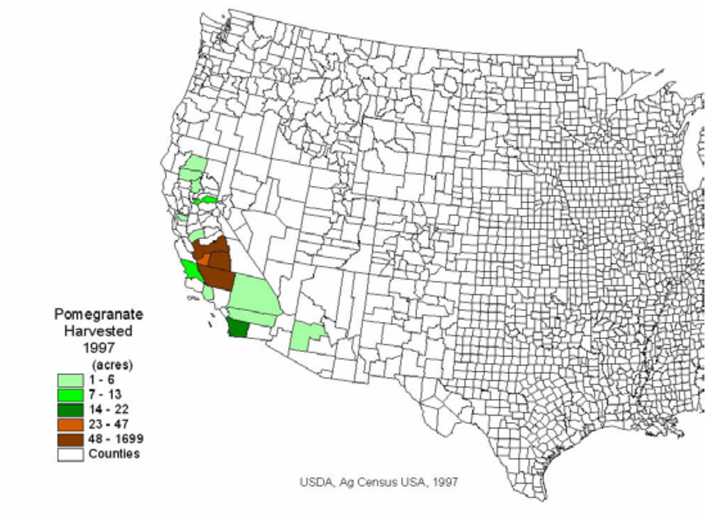
Map 27. Persimmon (*Diospyros* spp.)



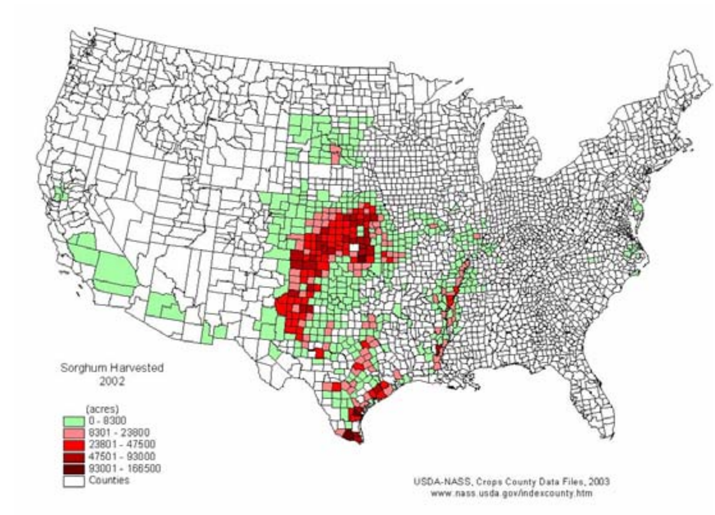
Map 28. Pimento (*Capsicum* spp.)



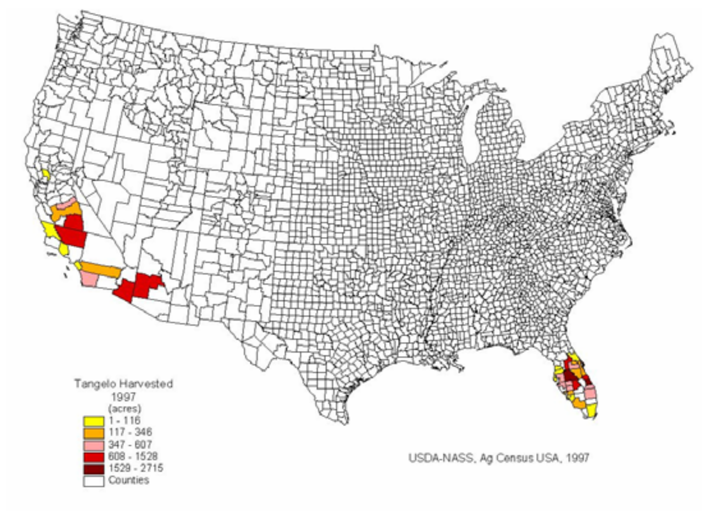
Map 29. Plum & Prune (*Prunus domestica*)



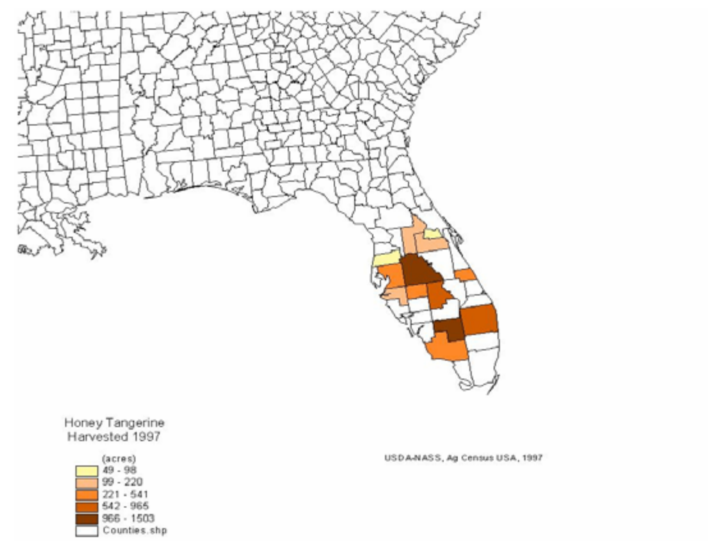
Map 30. Pomegranate (*Punica granatum*)



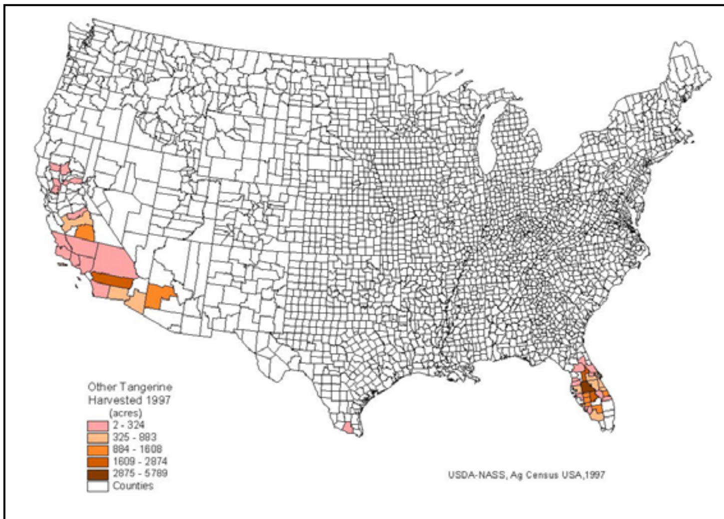
Map 31. Sorghum (*Sorghum* sp.)



Map 32. Tangelo (*Citrus tangelo*)



Map 33. Tangerine; honey (*Citrus reticulata*)



Map 34. Tangerine; other (*Citrus reticulata*)

Appendix C. Taxonomy of *Thaumatotibia leucotreta* (Meyrick) and related Tortricidae (prepared by M. DaCosta).

The species name *leucotreta* was removed from the genus *Cryptophlebia* and placed in *Thaumatotibia* by Komai (1999). The genus *Thaumatotibia* Zacher (1915) was not placed in a family when established, and was instead placed as a synonym of *Cryptophlebia* Walsingham (1899) (Nye and Fletcher 1991). Species of *Thaumatotibia* and *Cryptophlebia* are similar to each other externally and the two genera are related to each other. Komai (1999) lists the following characters common to both genera:

1) forewing broad (male broader than female), with a blackish triangular pretornal patch and with an accessory cell of chorda small or absent (chorda coincident with the margin of the discal cell)
2) hindwing with a short discal cell, especially in males
3) eighth tergite (and sometimes preceeding tergites) with a small patch of long scales
4) valva with a patch of very long, curled scales on the outer surface of the cucullus
5) tenth abdominal segment of pupa with a pair of strong spines along anal rise.

Thaumatotibia can be distinguished from *Cryptophlebia* on the basis of the following characters:

1) eighth tergite in male with a broadly sclerotized plate with convex posterior margin and laterally produced into curved points
2) sterigma indicated by an ovate or rectangular sclerite connecting posteriorly with a pair of ovate granulations with modified scales
3) corpus bursa with granular patch at juncture of ductus bursae.

The species *leucotreta* was placed in one of two species groups in *Thaumatotibia* by Komai (1999), the *leucotreta*-group, which is distinguished from the other species group, the *chaomorpha*-group, by (1) the presence of tufts of modified scales on the inner side of the hindtibia (usually), (2) an enlarged inner apical spur and (3) "normal" juxta. According to Bradley et al. (1979), male *T. leucotreta* are distinguished from other species by the specialized hindwing, which is slightly reduced and has a circular pocket of fine hair-like black scales overlaid with broad weakly shining whitish scales in the anal angle, and its heavily tufted hind tibia.

Descriptions of the external morphology as well as the genitalia of *Thaumatotibia leucotreta* (Meyrick) are provided.

Synonyms (from Bradley et al. 1979, Nye and Fletcher 1991, Komai 1999)

At the generic level:
Thaumatotibia Zacher,1915: 529-Heppner, 1980: 34 (as synonym of *Cryptophlebia*).
Type species: *Thaumatotibia roerigii* Zacher, 1915 [=*Argyroploce leucotreta* Meyrick, 1913] by monotypy

- *Argyroploce* Hübner, [1825]

- *Olethreutes* Hübner, 1822, Syst. -alphab. Verz.: 58-67, 69, 72. Type species: *Phalaena arcuella* Clerck, 1759, Icon. Insect. Rariorum 1: pl 10 fig. 8, by subsequent designation by Walsingham, 1895, Trans. Ent. Soc. Lond. 1895: 518.
- *Metriophlebia* Diakonoff, 1969: 89. –Razowski, 1977: 259. –Clarke, 1986: 162 (as synonym of *Cryptophlebia*), syn. n. Type species: *Eucosoma chaomorpha* Meyrick, 1929, by monotypy

At the species level:
leucotreta (Meyrick) 1913. Ann. Transv. Mus. 3: 267-336.

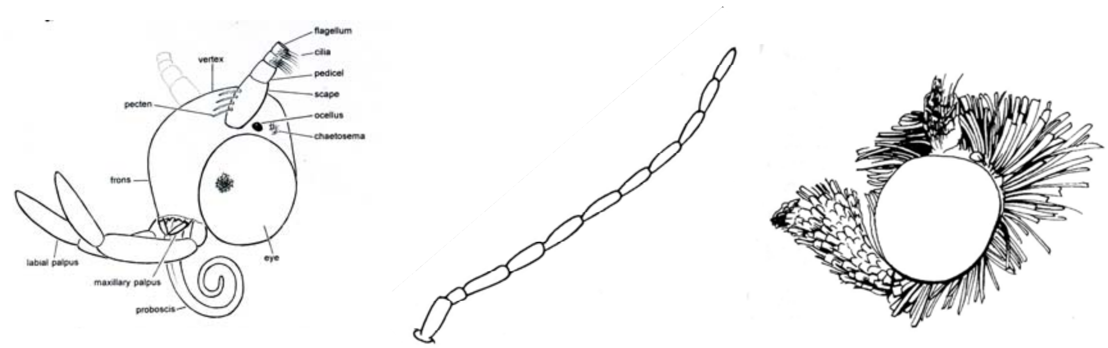
- *roerigii* Zacher, 1915: 529 Beiträge zur Kenntnis der westafrikanischen Planzenschädlinge.-Tropenpflanzer 18: 504-534.

Diagnosis of *Thaumatotibia leucotreta*:

[Description from Komai (1999).] Small to medium-sized, grayish-brown to dark brown/black moths with broad forewings (forewing index: 0.41-0.44mm in males, and 0.38-0.42mm in females) with a blackish triangular pretornal patch. Externally species of *Thaumatotibia* are similar to species of *Cryptophlebia*. Wing venation of *Thaumatotibia* is characterized by a small accessory cell delineated by the chorda from between R2 and R3 (closer to R3) to R4 or from between R1 and R2 (very close to R2) to between R5 and R5, or the absence of accessory cell (the chorda coincident with the margin of the discal cell), and by a short discal cell in the hindwing, especially in the male (0.42-0.43x length of the wing). Eigth tergum in male with a broadly sclerotized plate with convex posterior margin and laterally produced into curved points, with paired patches of long mane-like scales, but without a pair of long filiform scale tufts from shallow membranous pockets on each side of eighth tergum as in *Cryptophlebia*. Male genitalia are characteristic in the large, ovate valva (the outer surface with a patch of very long, curled scales, which is shared with *Cryptophlebia*), in the sacculus often with teeth distally, and in the juxta sometimes producing caudally a pair of denticulate, ovate lobes (the *chaomorpha*-group). The female genitalia is characterized by the sterigma indicated by an ovate or rectangular sclerite, connecting posteriorly with a pair of ovate granulations with modified scales, by the corpus bursae with a ring of granulation at the juncture of the ductus bursae, and sometimes a diverticulum ventrally or laterally.

Description:

Head: [Description from Komai (1999).] As in Figure C1. Frons with very dense, erect and moderately long scales. Antenna filiform, less than 2/3 length of forewing. Labial palps long and wavy; second segment widened distally, but scales appressed and rather short; terminal segment extends forward horizaontally, about 1/3 length of second, slender, with appressed scales, apex blunt.



A B C

Figure C1. Lateral views of head. A-Ventrolateral view of general moth head [Reproduced from Robinson et al. (1994)]. B-Filiform antenna [Reproduced from Borror et al. (1989)] C-Lateral view head of *Thaumatotibia hemitoma* (Diakonoff)-♂. [Reproduced from Komai (Komai 1999)]

Thorax: [Description from Komai (1999)] Posterior crest present. Hind tibia (as in Fig. C2) with modified scales on inner side, the inner apical spur enlarged with a batch of scales, the bases of which have a layer of secreting cells.

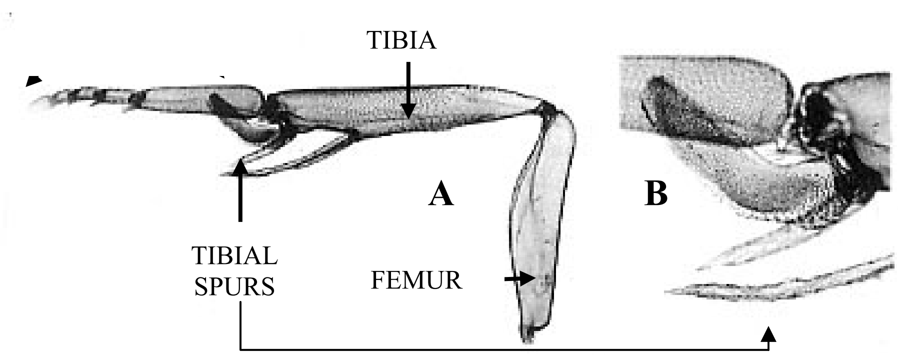
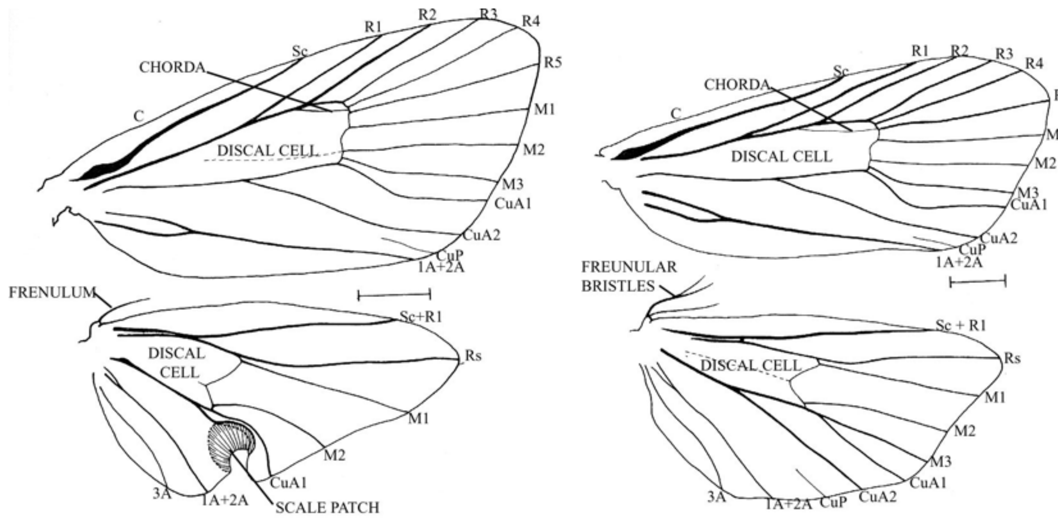


Figure C2. A-Hindtibia-modified scales and apical spur removed. B-Detail of spurs. [Reproduced from Komai (1999)]

Wings: [Description from Bradley et al. (1979).] Forewing pattern a mixture of bluish-gray, brown, black, and rust colored red-brown markings, the most conspicuous is the blackish triangular pre-tornal marking and the crescent-shaped marking above it, and a minute white spot in the discal area.

***Venation*:** As in Fig C3. There is a scent organ on the distal 2/3 of CuA2 on upper side. Its presence is indicated by concavity on wing membrane bounded with thickened ridges bearing the secreting cells [Zagatii and Castel quoted in Komai (1999)].



A B

Figure C3. Venation of *Thaumatotibia leucotreta* (Meyrick), A-male, B-Female. Veins: A-anal; C-Costa, Cu-Cubitus (CuA1-1st anterior cubitus; CuA2-2nd anterior cubitus; CuP-posterior cubitus); D-discal cell; M-Media, R-Radius, Sc-Subcosta.
[Reproduced from Komai (1999)]

***Abdomen*:** [Description from Komai (1999)] As in Fig C4. Second sternite with well developed anterolateral processes and sternal apodemes. Male abdominal scent organs: eighth tergite with a broadly sclerotized plate with convex posterior margin and laterally produced into curved points, densely covered with long scales which are easily removable.

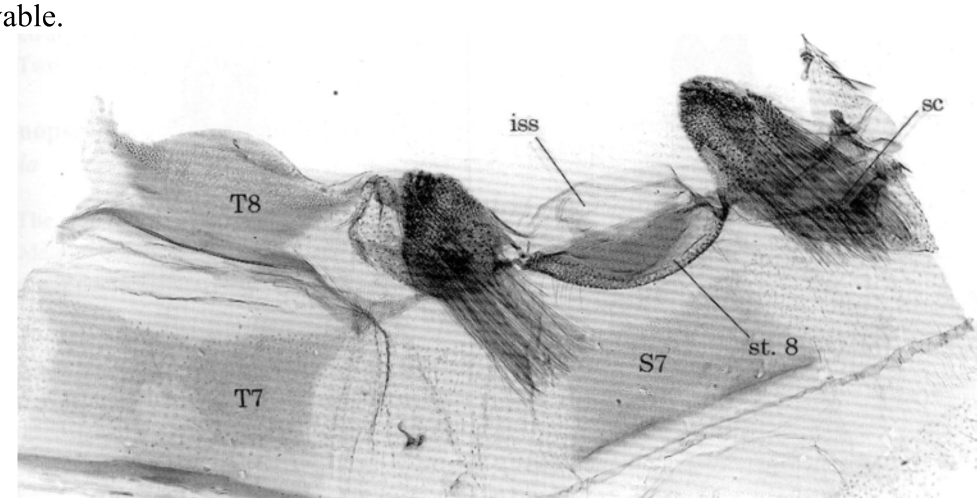


Figure C4. Post abdomen showing: 7th sternite (S7), 8th sternite (st. 8), 7th tergite (T7), 8th tergite (T8), intersegmental ventral sclerite between abdominal segments 8 and 9 (iss), scale-tufts of coremata (sc) [Reproduced from Komai (1999)]

***Male genitalia*:** [Description from Komai (1999)] As in Fig. C5. Tegumen a broad band, rounded apically; Aedeagus bulbous basally, narrowed at basal 1/4 to 1/3 and upcurved distally; vesica with series of fine cornuti. Juxta producing caudally a pair of denticuate, "normal" lobes. [Terminology follows Klots (1970).]

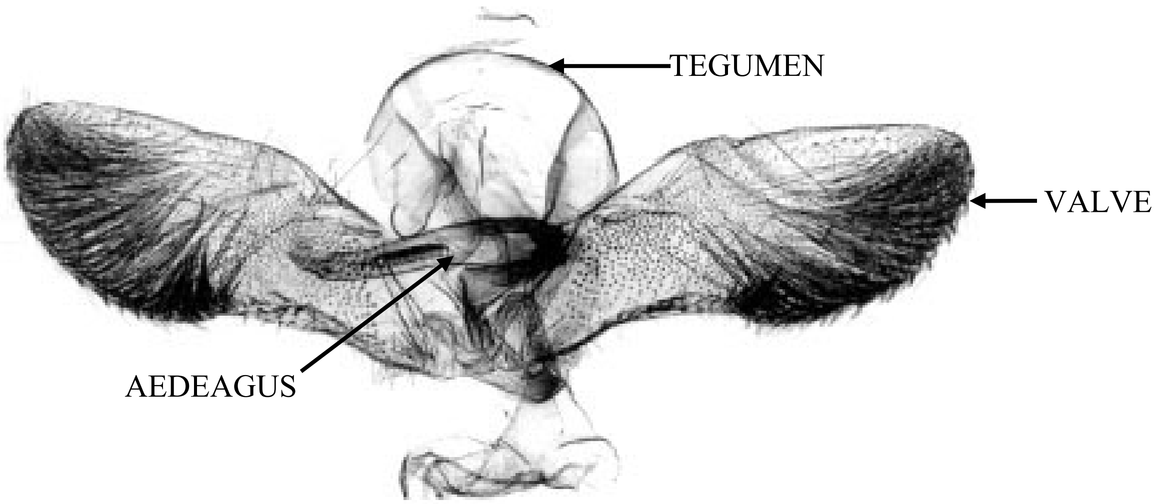


Figure C5. Ventral view male genitalia [Reproduced from Komai (1999)]

***Female genitalia*:** [Description from Komai (1999)] As in Fig. C6. Papillae anales "moderate". Anterior apophyses longer than posterior apophyses. Sterigma an ovate, or rectangular raised sclerite, connecting posteriorly with a pair of ovate granulations with modified scales. Ductus bursa long and narrow, ductus seminalis arising laterally, from posterior 1/4-1/5 of ductus bursa; bulla seminalis present; corpus bursae ovate, with a ring of granulation at juncture of ductus bursa with diverticulum laterally, with two large, curved, blade-shaped signa. Seventh sternite trapezoidal, posterior margin with shallow or deep excavation.

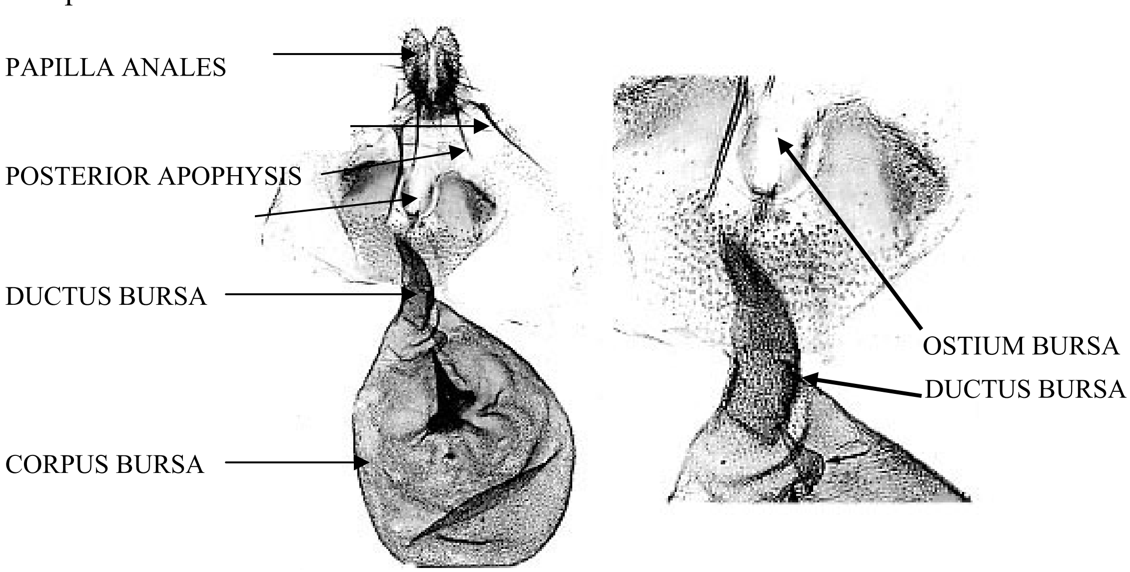


Figure C6. Genitalia *Thaumatotibia leucotreta* (Meyrick). Left-Entire genital apparatus, Right-ostium bursa and posterior part of bursa copulatrix [Reproduced from Komai (1999)]

***Larva*:** [Description from Komai (1999).] Body length of mature larva 15mm. Head yellowish-brown. Body orange or pink in final instar. Pinacula large, darker than body color. Spiracle on A8 near the posterior margin. Prolegs with 31-40 crochets arranged in a biordinal circle. Anal fork present. Chaetotaxy As in Fig. C7: SD1 and SD2 on same pinaculum on A9; SV group on A1-A6 trisetose, on A7 and A8 bisetose, A9 unisetose; L group trisetose on A9.

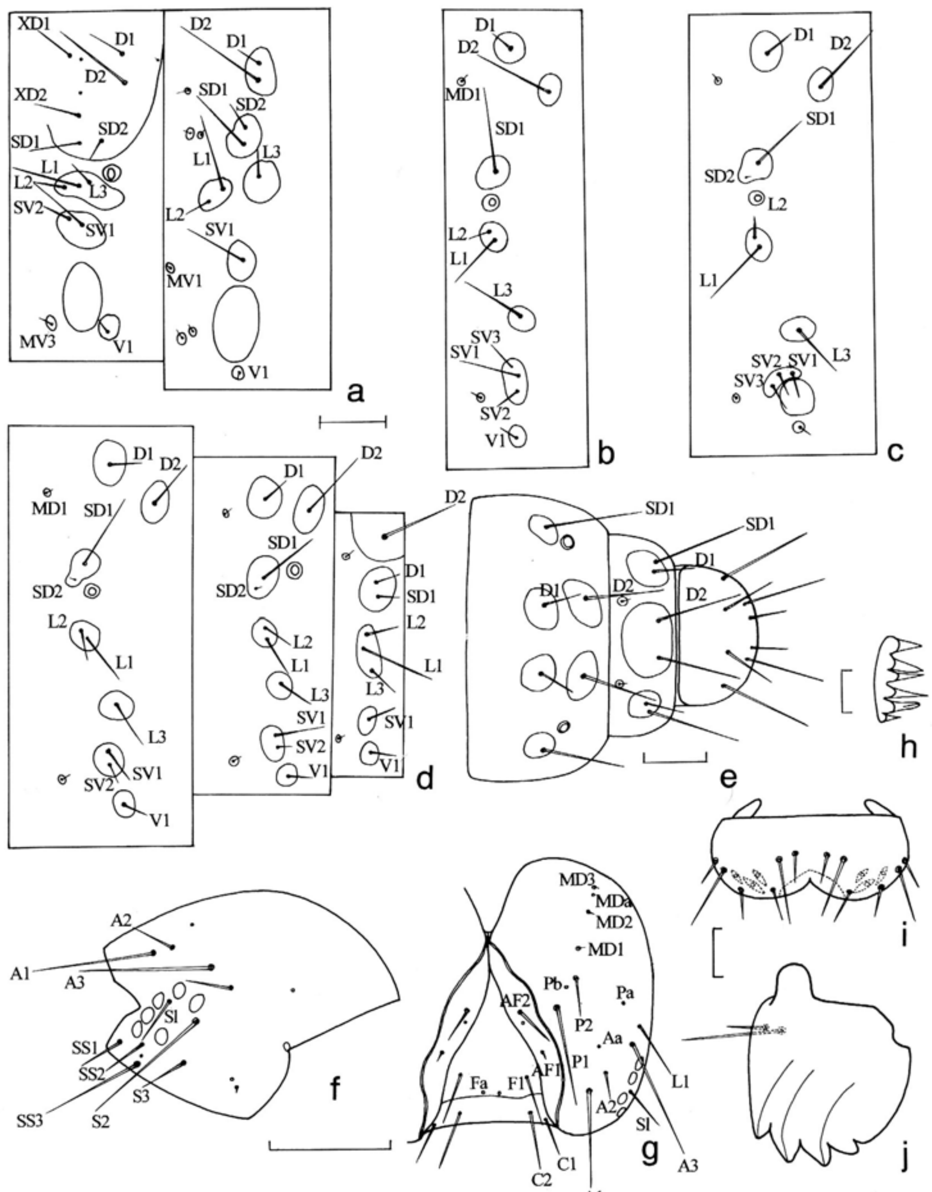


Figure C7. Setal map of *Thaumatotibia leucotreta*; drawing scale a-g: 0.5mm, h-j: 0.1 mm [Reproduced from Komai (1999)]

***Pupa*:** [Description from Komai (1999)] As in Fig. C8. Body length 6-10mm. Body pale yellowish-brown. Similar to *Cryptophlebia*. Spiracles transversely ovate. A2-A7 with two rows of dorsal spines; A8-A10 with one row of strong spines, in male A8 with two rows of dorsal spines; A10 with a pair of strong spines along anal rise, without hooked setae except two pairs along anal rise.

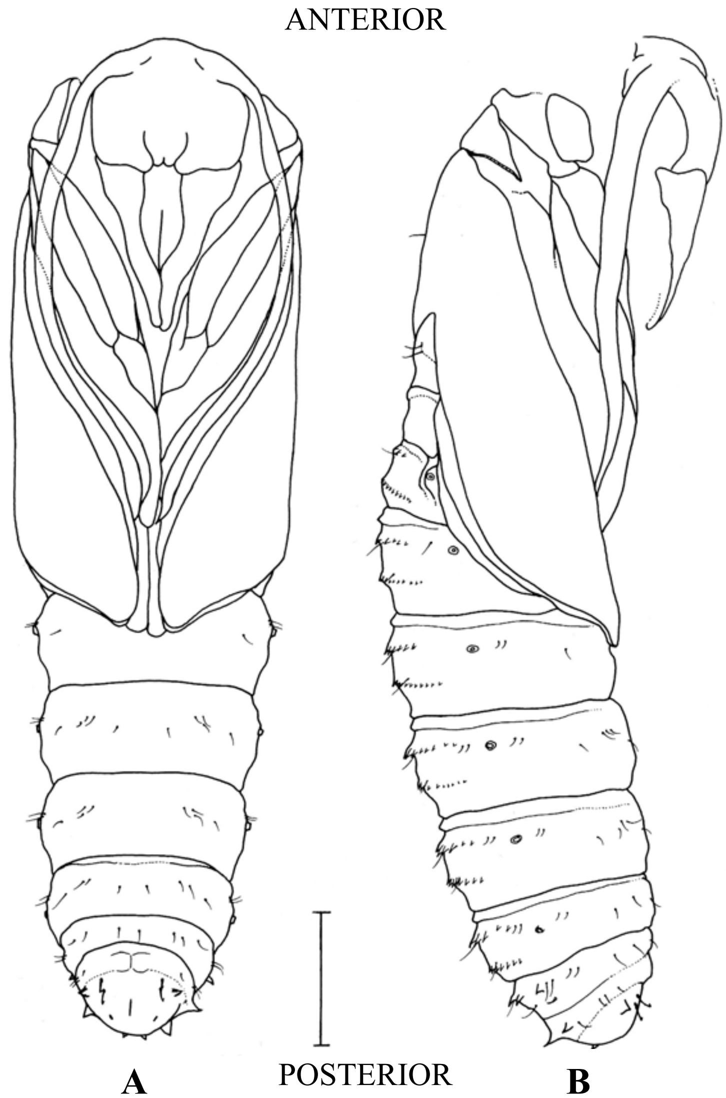


Figure C8. Pupa of *Thaumatotibia sp*. A-Ventral view, B-Lateral view (scale = 1 mm) [Reproduced from Komai (1999)]

Similar species: *Cydia pomonella* (Linnaeus)-the codling moth [occurs in the US]

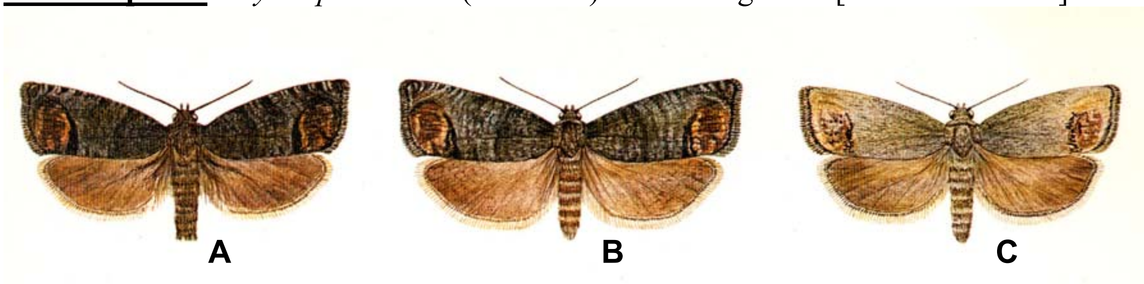


Figure C9. Dorsal views of *Cydia pomonella* (Linnaeus) A-male, B & C-female (to illustrate degree of morphological variation within a sex).
[Reproduced from Bradley et al. (1979)]

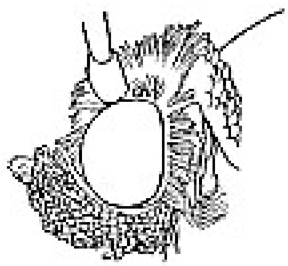


Figure. C10. Lateral view of head of *Cydia pomonella* (Linneaus)
[Reproduced from Bradley et al. (1979)]

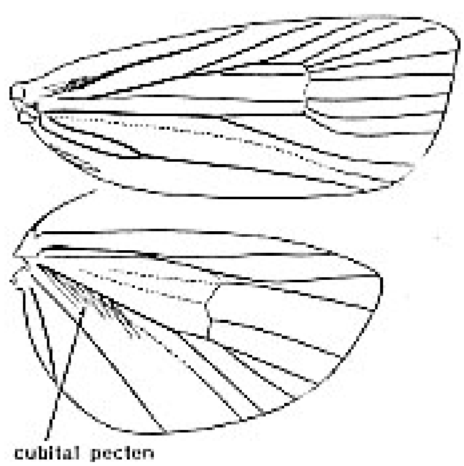


Figure C11. Venation of *Cydia pomonella*
[Reproduced from Bradley et al. (1979)]

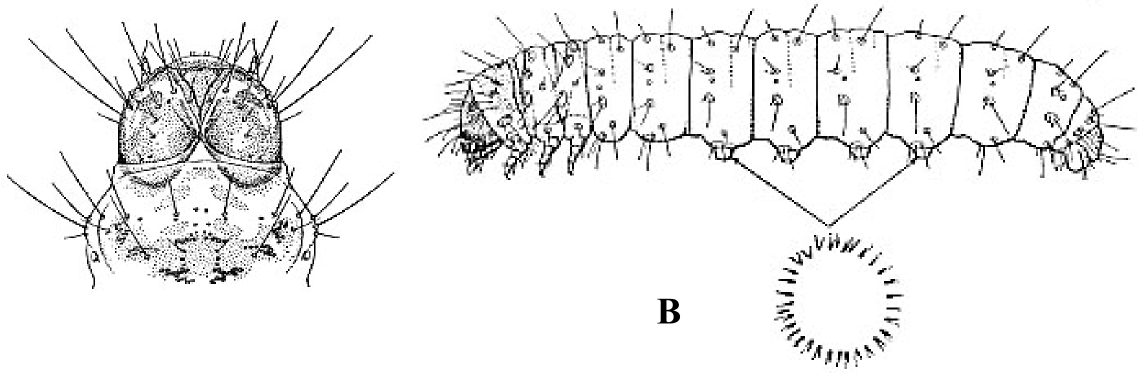


Figure C12. Larva of *Cydia pomonella* (Linneaus). A-Dorsal view of head, B-lateral view of body; pattern of crochets [Reproduced from Bradley et al. (1979)]

Appendix D. Biology of *Thaumatotibia leucotreta*

Population phenology

Thaumatotibia leucotreta has 2-10 generations annually (Daiber 1980, Couilloud 1994, Begemann and Schoeman 1999). The number of generations is determined by several factors including temperature, food availability/quality, photoperiod, humidity, latitude and the effect of predators and diseases (Catling and Aschenborn 1974, Daiber 1979, 1980, Newton 1988a, b, Newton and Crause 1990, Couilloud 1994, Begemann and Schoeman 1999). With an uninterrupted supply of plant hosts *T. leucotreta* remains active throughout the year (Blomefield 1978, Newton 1988b). Four generations can occur per season on navel oranges (Daiber 1975). Five generations can be completed in South Africa (Daiber 1980), although a laboratory study suggested 10 generations annually are possible in this region (Begemann and Schoeman 1999).

Stage specific biology

Adults. The life span of adults depends largely on temperature, regional climatic conditions and host availability (Daiber 1980, Couilloud 1994). Moths may live 1-6 weeks, or up to ~28 weeks under favorable winter conditions in South Africa (Daiber 1980, Couilloud 1994). At warmer temperatures (e.g., 10-15°C), reproduction is generally greater, but life span is shorter, than at cooler temperatures (e.g., 20-25°C) (Daiber 1980). On average, females live longer than males (Daiber 1980). The ratio of males to females is 1:2 (Couilloud 1994).

Emergence occurs early in the morning (Couilloud 1994). Moths are active at night and spend daytime hours resting on shaded portions of the host (Blomefield 1978, Couilloud 1994). Moth activity increases with the onset of host flowering (Newton 1989a). Moths can mate several times per day (Couilloud 1994). Oviposition occurs on or near developing fruit after petal fall (Daiber 1975, Newton 1989b, Ochou 1993).

Thaumatotibia leucotreta females prefer specific parts of the host plant for oviposition. Females tend to choose smooth, non-pubescent surfaces for egg-laying. On cotton, green bolls are preferred (Couilloud 1994). On peach, eggs are deposited near fruit on smooth leaves (Blomefield 1978)(Newton, 1988a). Moths also tend to select areas on fruit with damage (Blomefield 1978, Newton and Crause 1990).

The onset and degree of oviposition vary with temperature and host plant (Daiber 1980, Chambers et al. 1995). Egg-laying begins 2-3 days after emergence (Blomefield 1978). Eggs are laid singly or in small groupings of 2-4 “overlapping like tiles” on or near fruit surfaces (Daiber 1980, Blomefield 1989, Newton and Crause 1990, Couilloud 1994). Eggs are only laid between 5pm and 10pm (Daiber 1980). A female will generally produce between 87-456 eggs depending on temperature [within a range of 15-25°C] (Daiber 1980). However, individual female fecundity can vary from 5-799 eggs (Daiber 1980).

Eggs. Egg development takes 2-22 days depending on temperature (Daiber 1979). Eggs are extremely sensitive to cold temperatures and extended periods of low humidity. Temperatures below 0°C over a 2-3 day period can kill eggs (Blomefield 1978, Daiber 1979).

Larvae wander for a short while before tunneling into the host fruit, where most of the larval stage is spent (Blomefield 1978, La Croix and Thindwa 1986b, Newton and Crause 1990, Couilloud 1994). The duration of this stage may vary widely (from 4-173 days), depending on temperature and host plant (Blomefield 1978; Daiber 1979b)(Daiber 1979, Daiber 1989, Couilloud 1994). *Thaumatotibia leucotreta* has up to 5 instars (Bradley et al. 1979, Couilloud 1994). The last instar is typically completed in fruit. A larva prepare to pupate by leaving the fruit and spinning a cocoon with silk and soil particles (USDA 1984). Pupation occurs on the soil surface, in the soil, in crevices under bark, in dropped fruit or in debris (Blomefield 1978, USDA 1984, La Croix and Thindwa 1986a, Daiber 1989, Newton and Crause 1990).

Pupae emerge slightly from the cocoon before adult emergence takes place. "The empty pupal skin usually remains attached to the cocoon" (Daiber 1989).
Under laboratory conditions, the pupal stage lasts between 2-33 days, depending on temperature (Daiber 1989). Pupae are also sensitive to cold temperatures and heavy rainfall (Daiber 1989). Pupae that have completed ¼ to ½ of their development tend to be more cold resistant than older or younger pupae (Myburgh and Bass 1969).

Several studies have described the developmental threshold and accumulated degree days necessary for the completion of each life stage (Table D1).

Table D1. Developmental threshold and degree day requirements for *Thaumatotibia leucotreta*

Stage	Developmental threshold (˚C)	Degree Days (± SE)	Notes	Reference
Egg	11.93	51.2-69.3	Lab study	(Daiber 1979)
	11.7	69.4±3.2	Calculated from author's data	(Daiber 1975)
Larva	11.6-12.5	156	Lab study	(Daiber 1979)
Pupa	11.9	174 (females) 186 (males)	Lab study	(Daiber 1979)
Adult	8	232±4.2	Male life span; calculated from author's Table 1	(Daiber 1980)
	8.1	229.8±3.8	Male life span; calculated from author's Table 5	(Daiber 1975)
	9.5	243.5±12.3	Female life span; calculated from author's Table 1	(Daiber 1980)

Stage	Developmental threshold (˚C)	Degree Days (± SE)	Notes	Reference
	9.7	237.8±10.9	Female life span; calculated from author's Table 5	(Daiber 1975)
	6.4	242.8±18.1	Oviposition period; calculated from author's Table 5	(Daiber 1975)
	12.2	79.2±3.8	Time to 50% eggs laid; calculated from author's Table 1	(Daiber 1980)
	15	12.8±2.8	Preoviposition period; calculated from author's Table 5	(Daiber 1975)