RECOMMENDATIONS OF THE TECHNICAL WORKING GROUP

for the

LIGHT BROWN APPLE MOTH PROGRAM

January 25, 2007

These recommendations were developed during a meeting of the Technical Working Group (TWG) in San Diego, California, December 13-14, 2007

Overriding recommendation: The U.S. Department of Agriculture (USDA) Animal and Plant Health Inspection Service (APHIS) and the California Department of Food and Agriculture (CDFA) should maintain the long-term goal of eradicating light brown apple moth (LBAM), *Epiphyas postvittana* (Walker), from California.

Overall strategy: The TWG recommends the following strategy in achieving the long-term goal of LBAM eradication in California:

- Maintain a comprehensive regulatory program, with proven regulatory treatments to minimize human-assisted transport of LBAM from the currently infested area into uninfested areas.
- Continue ongoing detection trapping efforts throughout California. Expand and standardize LBAM survey efforts on a national scale.
- Proceed with eradication by integrating tactics and methods that have proven effective.
- Rapidly implement a technical component of the LBAM program, which would include program and population assessment, and research and development of methods needed for best achieving program goals. The most urgent technical need at this time is testing to identify the most efficacious formulations and methods for conducting area-wide mating disruption.

Progress to date: The TWG commends the program for the substantial progress it has made to date.

- The LBAM population in California has been delimited. This required rapid implementation and operation of an extensive trapping system.
- The regulatory framework implemented by the program appears to have been effective in limiting human-mediated movement of the pest.
- "Outlier" populations were delimited and successfully eliminated.
- Work toward incorporating trapping data into an electronic geo-referenced database (ISIS) has been initiated.

Specific Recommendations:

- *Eradication strategy*

Eradication of the LBAM population will not be a simple endeavor, and will likely take several years to accomplish. In addition to mating disruption, the program should consider using a "multi-pronged" integrated approach (insecticide, attract-and-kill, biological control, and SIT). Overall, the TWG suggests approaching eradication in a step-wise fashion rather than attempting to eradicate throughout the entire infested area simultaneously. Containment measures must be in place and rigorously enforced in areas not initially targeted for eradicative activities. This should help ensure eventual success as it will allow the program to focus its eradication resources within a manageable area while containing and conducting suppression activities elsewhere in anticipation of eventual initiation of eradicative treatments. The TWG also suggests (as has been done) starting the eradication strategies at the southern end of the infestation, as this is the area from which risk of transporting LBAM to uninfested areas is greatest.

- *Mating disruption.*

At this time, aerial application of mating disruption formulations remains the tool of choice for application across broad areas. Substantial development efforts would be needed before other control methods such as sterile insects or biological controls would be ready for program use. In addition, uses of biological control for eradication may be limited. Because new and longer lasting formulations of the mating disruption products are becoming available, the TWG does not recommend any additional aerial applications of mating disruption formulations until the new formulations are tested and the most effective combination of formulation, application rate, and application methods for new formulations has been identified (see Research and Development needs). The TWG does, however, recommend that the program proceed with the purchase of neat pheromone for disruption formulations.

- *Ground treatment options.*

The program should initiate a focused ground treatment component within highly infested core areas. This approach could be used both to augment mating disruption treatments (e.g., Soquel) and simply to maintain populations at reduced levels to minimize risk of spread (e.g., Golden Gate Park). "Softer" insecticides with proven track records against LBAM could be used, such as *Bt* or spinosad. In addition, the use of other potential tools such as Attract and Kill technology should be explored for ground treatments.

- *Survey*

Data management - the LBAM program should work toward maintaining trapping data in electronic geo-referenced databases. In fact, this type of trapping information would be beneficial for all detection programs. These databases should include all pertinent information, including inspection dates, positions, number of moths captured, trap conditions, etc. of all traps. Initial (field) recording of data should be done using GPS-capable PDA's. The TWG realizes that, given the scale of these programs, moving from written records to electronic databases will not be quick or easy. In the long run, though, this will greatly simplify tasks associated with acquiring, storing, transferring, analyzing, evaluating, and assuring the quality of trapping survey data.

National survey - an effective national survey is needed to ensure that the eradication program is not being undertaken in one area while other infestations are present at other locations in the U.S. The TWG understands that such surveys have occurred in a number of states in 2007 and recommends expanding the survey to all states where LBAM could potentially become established.

Phenology traps - phenology traps were placed and maintained per previous TWG recommendations but the 2007 data indicate that the system needs to be expanded upon and enhanced to provide timely data analysis.

Research and Development Needs

The TWG has identified the following research and development necessary to the success of the eradication program, including the appointment of a dedicated coordinator in support of the program:

- ***Mating Disruption***

  As new formulations become available, rapidly identify a combination of formulation and application rate, and application method that effectively reduces mating enough to suppress LBAM population levels typical of those encountered in California. The testing should include the following:

  - Ideally, open-field tests of candidate formulations should be undertaken using "wild" LBAM populations. To get such testing done in short order, these would have to be run in the southern Hemisphere – most likely in New Zealand.
  - Benchmarks for the efficacy of mating disruption need to be established by the TWG over the next few months.
  - Shin Etsu twist-ties can be used as a "positive control" standard.
  - Aerial application based on methods used in the CA program would be ideal.
  - Other types of tests, such as field-cage mating trials within smaller treated areas can be used as an augmentative or perhaps even an alternative method of evaluating formulations.

- Field studies should be backed up with lab evaluations of release rates from different formulations, resistance to wash-off, etc.
- Testing should be run simultaneously to relate mating success to trap catch at different lure-loading rates.
- In less time-critical testing, ground application of flake and sprayable formulations should be evaluated as an alternative to hand-applied disruption formulations (e.g., twist-ties) for treatment of small- to medium-sized areas.
- Evaluate and quantify the effect of levels of the *Z* isomer of 11-14:Ac (inhibits response to the pheromone) and *E9,E11*-14:Ac (the minor component of the pheromone) on mating disruption.
- Determine how vertical distribution of the mating disruption formulation affects efficacy.

- ***Sterile Insect Technique (SIT)***

  The program should pursue development of SIT as an alternative and/or augmentative method of suppressing/eradication of LBAM populations.

  - Develop mass rearing methodology for SIT as well as potential production of biological control agents (parasites, pathogens).
  - Develop rearing capacity (perhaps in Hawaii, or within the generally infested area of California). Explore the possibility of producing the diet at the pink bollworm rearing facility in Phoenix, AZ.
  - Complete dose-sterility testing for both conventional (complete) and inherited (F1) sterility.
  - Assess competitiveness of sterile LBAM (irradiated generation) and F1-sterile larvae and moths.
  - Assess efficacy of males-only vs. both sex releases of LBAM.
  - Identify and evaluate appropriate methods for distributing and releasing sterile LBAM adults.

Additional research and development recommendations (unprioritized)

- Continue ongoing efforts to evaluate candidate insecticides as regulatory treatments for nursery stock and other commodities.
- Evaluate effectiveness of insecticides for control of LBAM populations, with focus on more biorational insecticides such as *Bt* and spinosyns. Where possible, screen these insecticides against LBAM from California populations.
- Develop information on population dynamics and ecology of LBAM in North America.
- Evaluate and develop biological control methods for LBAM: augmentative releases (e.g., Trichogramma), classical biological control, and insect pathogens (e.g., nucleopolyhedrosis virus). Develop information on parasitism and

predation of LBAM by natural enemies that are native to, or were previously introduced into, California.

- Evaluate effectiveness of mobile mating disruption of LBAM.
- Develop population and phenology models for LBAM in North America. Test (validate) available phenology and population model(s) using New Zealand, Australian, and United States trapping data. Climex and Dymex models are available but need validation. Determine the degree of synchrony of generations within U.S. LBAM populations.
- Optimize traps, lures, release rates, and methods of deployment (e.g., trap placement parameters such as height).
- Determine sensitivity of survey traps (distance/capture curves) for LBAM (including food-bait as well as pheromone traps).
- Determine LBAM dispersal distances under California conditions (females, males, larvae).

Mini Risk Assessment
Light brown apple moth, *Epiphyas postvittana* (Walker) [Lepidoptera: Tortricidae]

Robert C. Venette, Erica E. Davis, Michelle DaCosta, Holly Heisler, & Margaret Larson
Department of Entomology, University of Minnesota
St. Paul, MN 55108
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Introduction

Epiphyas postvittana is a highly polyphagous pest that attacks a wide number of fruits and other plants. This species has a relatively restricted geographic distribution, being found only in portions of Europe and Oceania (van Den Broek 1975, Terauds 1977, IIE 1991, Danthanarayana et al. 1995, Suckling et al. 1998). The pest is native to Australia but has successfully invaded other countries (Danthanarayana 1975). The likelihood and consequences of establishment by *E. postvittana* have been evaluated in pathway-initiated risk assessments. *Epiphyas postvittana* was considered highly likely of becoming established in the US; the consequences of its establishment for US agricultural and natural ecosystems were judged to be high (i.e., severe) (Lightfield 1995).

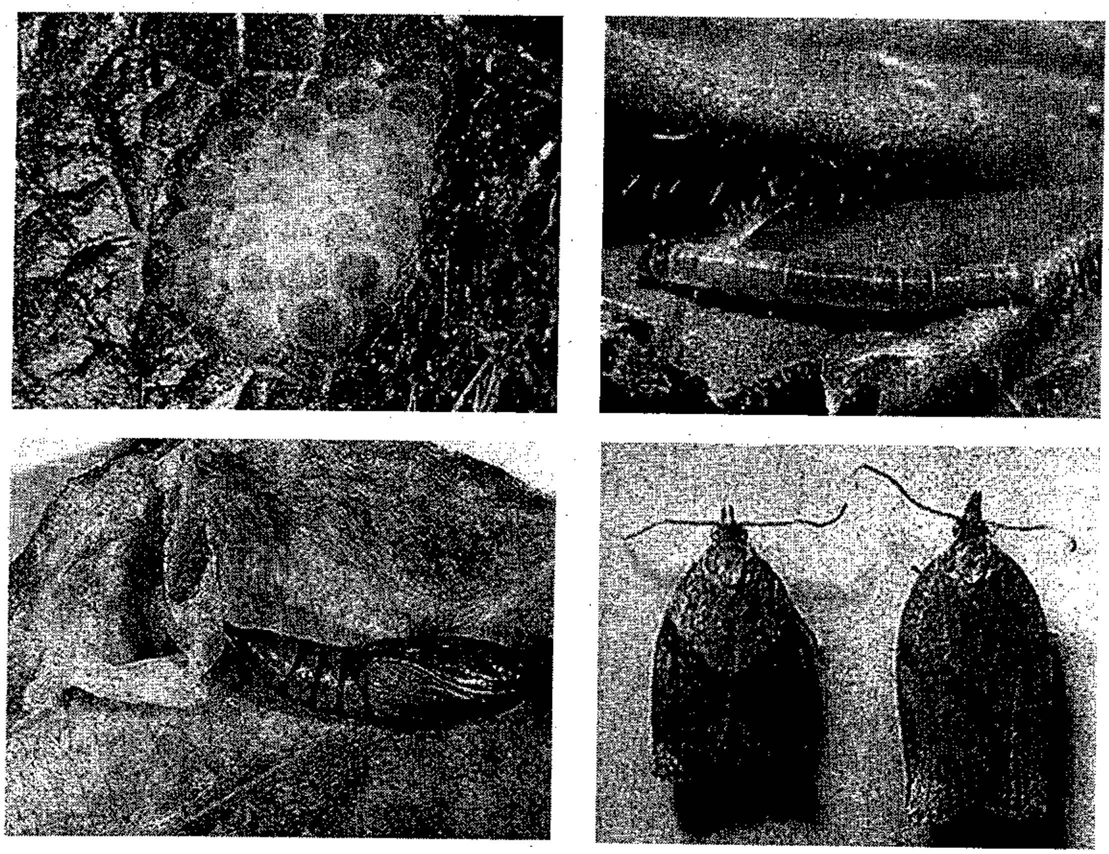

Figure 1. Life stages of *Epiphyas postvittana*: (top left) eggs; (top right) larva; (bottom left) pupa, (bottom right) adults, male is on the left. (Photos from http://www.hortnet.co.nz/key/keys/info/lifecycl/lba-desc.htm)

1. **Ecological Suitability. Rating: High.** *Epiphyas postvittana* is found in northern Europe, southern Australia, New Zealand, and Hawaii (IIE 1991). The climate within its range can be generally characterized as temperate, tropical, or dry (CAB 2003). The currently reported global distribution of *E. postvittana* suggests that the pest may be most closely associated with deserts and xeric shrubland; temperate broadleaf and mixed forests; temperate grasslands, savannahs, and shrublands; and tropical and subtropical moist tropical broadleaf forests. Based on the distribution of climate zones in the US, we estimate that approximately 80% of the continental US may be climatically suitable for *E. postvittana* (Fig. 2). See Appendix A for a more complete description of this analysis.

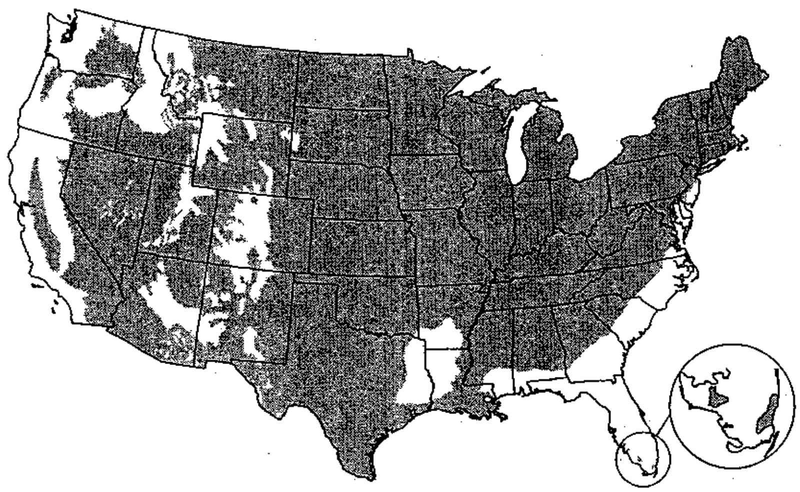

Figure 2. Predicted distribution of *Epiphyas postvittana* in the continental US. Southern Florida is enlarged for detail.

2. **Host Specificity/Availability. Rating: Low/High.** *Epiphyas postvittana* has a host range in excess of 120 plant genera in over 50 families (Geier and Briese 1981) with preferences for hosts in the families Compositae, Leguminosae, Polygonaceae, and Rosaceae (Danthanarayana 1975). Host plants include: *Adiantum* sp., *Aguilegia* sp., *Amaranthus* sp., *Arbutus* sp., apple (*Malus domestica, Malus* spp.), apricot (*Prunus armeniaca*), *Artemesia* sp., *Astartea* sp., *Aster* sp., avocado (*Persea americana*), *Baccharis* sp., black alder/European alder (*Alnus glutinosa*), blackberry and raspberry (*Rubus* spp.), black poplar (*Populus nigra*), blueberry (*Vaccinium sp.*), *Boronia* sp., *Brassica* sp., *Breynia* sp., broad bean (*Vicia faba*), broadleaf dock (*Rumex obtusifolius*), *Bursaria* sp., butterfly bush (*Buddleia* spp.), *Calendula* sp., *Callistemon* sp., camellia (*Camellia japonica*), *Campsis* sp., capeweed (*Arctotheca calendula*), *Cassia* sp., *Ceanothus* sp., Chinese gooseberry (*Actinidia chinensis*), *Choisya* sp., chrysanthemum (*Chrysanthemum* spp., *Chrysanthemum* x *morifolium*), citrus (*Citrus* spp.), *Clematis* sp., *Correa* sp., cotoneaster (*Cotoneaster* spp.), *Clerodendron* sp., clover (*Trifolium repens, Trifolium* spp.), *Cupressus* sp., curled dock (*Rumex crispus*), currant (*Ribes* spp.), *Cydonia* sp., *Dahlia* sp., *Datura* sp., *Daucus* sp., *Dodonaea* sp., *Eriobotrya* sp., *Eriostemon* sp., *Escallonia* sp., eucalyptus (*Eucalyptus* spp.),

euonymus (*Euonymus* spp.), fat-hen (*Chenopodium album*), *Forsythia* sp., *Fortunella* sp., fox's brush/heliotrope/valerian (*Centranthus* spp.), *Gelsemium* sp., *Genista* sp., *Gerbera* sp., gorse (*Ulex europaeus*), grape (*Vitis vinifera, Vitis* spp.), *Grevillea* sp., *Hardenbergia* sp., hawthorn (*Crataegus* spp.), hebe (*Hebe* spp.), *Helichrysum* sp., hop (*Humulus lupulus*), horn of plenty (*Feijoa sellowiana*), ivy (*Hedera helix, Hedera* spp.), jasmine (*Jasminum* spp.), *Juglans* sp., kiwifruit (*Actinidia deliciosa*), *Lathyrus* sp., *Lavendula* sp., *Leucodendron* sp., *Leptospermum* sp., *Linus* sp., litchi (*Litchi chinensis*), *Lonicera* sp., lucerne/alfalfa (*Medicago sativa*), *Lupinus* sp., *Lycopersicum* sp., *Macadamia* sp., malabar ebony (*Diospyros* spp.), *Mangifera* sp., *Melaleuca* sp., *Mentha* sp., *Mesembryanthemum* sp., *Michelia* sp., *Monotoca* sp., montbretia (*Crocosmia* spp.), *Myoporum* sp., oak (*Quercus* spp.), *Oxalis* sp., *Parthenocissus* sp., peach (*Prunus persica*), pear (*Pyrus* spp.), *Pelargonium* sp., *Persoonia* sp., *Petroselinum* sp., persimmon (*Diospyros kaki*), *Philadelphus* sp., *Photinia* sp., *Pittosporum* sp., pine (*Pinus* muricata, *P.* radiata, Pinus spp.), plantain / ribwort (*Plantago lanceolata*), *Platysace* sp., *Polygala* sp., *Polygonum* sp., poplar / cottonwood (*Populus nigra, Populus* spp.), potato (*Solanum tuberosum*), privet (*Ligustrum vulgare, Ligustrum* spp.), *Pteris* sp., *Pulcaria* sp., *Pyllanthus* sp, *Pyracantha* sp., *Ranunculus* sp., *Raphanus* sp., *Reseda* sp., raspberry (*Rubus idaeus*)/ boysenberry/olallieberry (*Rubus* spp.), rose (*Rosa* spp.), *Salvia* sp., *Senecio* sp., Scotch broom (*Cytisus scoparius*), *Sida* sp., *Sisymbrium* sp., *Smilax* sp., *Sollya* sp., St. John's wort (*Hypericum perforatum*), strawberry (*Fragaria* sp.), *Tithonia* sp., *Trema* sp., *Triglochin* sp., *Urtica* sp., *Viburnum* sp., *Vinca* sp., wattle (*Acacia* spp.), and willow (*Salix* spp.). (Danthanarayana 1975, Terauds 1977, Geier and Briese 1980, 1981, Nuttal 1983, Winter 1985, Charles et al. 1987, Tomkins et al. 1989, IIE 1991, Zhang 1994, Danthanarayana et al. 1995, Lo et al. 1995, Stevens 1995, Charles et al. 1996, Dentener et al. 1996, Burnip and Suckling 1997, Glenn and Hoffmann 1997, Whiting and Hoy 1997, Foster and Howard 1998, Suckling et al. 1998, Brown and Il'ichev 2000, Suckling et al. 2001, Brockerhoff et al. 2002, CAB 2003).

See Appendix B for maps showing where various hosts are grown in the continental US.

3. **Survey Methodology. Rating: Medium.** Visual inspections have been used to monitor population dynamics of *E. postvittana* eggs and larvae. In grape, 40 vines were inspected per sampling date (Buchanan 1977). In apple and other tree fruits, 200 shoots and 200 fruit clusters (10 of each on 20 different trees) are often inspected (Bradley et al. 1998, Lo et al. 2000). Egg masses are most likely to be found on leaves (USDA 1984). Larvae are most likely to be found near the calyx or in the endocarp; larvae may also create "irregular brown areas, rounds pits, or scars" on the surface of a fruit (USDA 1984). Larvae may also be found inside furled leaves, and adults may occasionally be found on the lower leaf surface (USDA 1984).

Sex pheromone has been identified from *E. postvittana* and used to monitor male flight periods. Two key components of the pheromone are (*E*)-11-tetradecenyl acetate and (*E,E*)-(9,11)-tetradecadienyl acetate (Bellas et al. 1983). These compounds in a ratio of 20:1 are highly attractive to males (Bellas et al. 1983). To monitor male flight activity in stands of Monterey pine (*Pinus radiata*) in New Zealand, 100 µg of a 95:5 ratio of (*E*)-11-tetradecenyl acetate: (*E,E*)-(9,11)-tetradecadien-1-yl acetate was placed on a rubber septum and used in delta traps with a 20 cm x 20 cm sticky base (Brockerhoff et al. 2002). Traps were placed 6.5 ft (2 m) above ground level without any understory vegetation (Brockerhoff et al. 2002). A similar procedure has been used in apples (Thomas and Shaw 1982, Suckling et al. 1990, Suckling and Shaw 1992, Bradley et al. 1998) and caneberries (e.g., raspberries and blackberries, Charles et al. 1996). Delta traps were placed 5 ft (1.5 m) above the ground, and lures were changed every 6 weeks (Thomas and Shaw 1982, Suckling et al. 1990, Suckling and Shaw 1992).

For a regional survey of tortricids, delta traps (20x20 cm sticky, flat base) were placed in each of 12 apple orchards (Cross 1996). Delta traps have also been used with pheromone lures to monitor male flights of *E. postvittana* in stone fruits (Brown and Il'ichev 2000). Frequently, traps are placed in the center of an orchard at densities in the range of 1 trap per 0.37-5 acres [=0.14-2 ha] (Bradley et al. 1998). In vineyards, pheromone traps also have been placed at a density of approximately 1 trap per 5 acres [=2 ha] (Glenn and Hoffmann 1997).

Foster and Muggleston (1993) provide a detailed analysis of different designs of delta traps. In general, they found that traps with a greater length (i.e., the distance between the two openings of the trap) capture significantly more *E. postvittana* than shorter traps. This effect is not related to saturation of smaller sticky surfaces with insects or other debris. The addition of barriers to slow the exit of an insect from a trap also improves catch. In a separate analysis, Foster et al. (1991) found that placing the pheromone lure on the side of the trap helped to improve trap efficiency. The orientation of the trap relative to wind direction did not affect the number of *E. postvittana* that were attracted to the pheromone or were subsequently caught by the trap (Foster et al. 1991).

Adults are also attracted to fruit fermentation products as a 10% wine solution has been used as an attractant and killing agent for adults (Buchanan 1977, Glenn and Hoffmann 1997). The dilute wine (670 ml) in 1 liter jars was hung from grapevines on the edge of a block of grapes (Buchanan 1977).

Blacklight traps have been used to monitor adults of *E. postvittana* (Thwaite 1976).

4. **Taxonomic Recognition. Rating: Low.** *Epiphyas postvittana* may be confused with *E. pulla* [not known in US] and *E. liadelpha* [not known in US], and larvae of several leafrollers within its range (CAB 2003). Identity of the species must often be confirmed by examination of adult genitalia. Molecular diagnostics

based on PCR amplification of ribosomal DNA have been developed and are especially useful for the identification of immature specimens (Armstrong et al. 1997).

For a detailed description of the morphology and taxonomy of *E. postvittana*, see Appendix C.

5. **Entry Potential. Rating: Low.** Interceptions of *E. postvittana* or "*Epiphyas* sp." have only been reported 55 times since 1984, primarily on rosaceous host plants (USDA 2003). Annually, about 3 (±0.7 standard error of the mean) interceptions of *E. postvittana* or "*Epiphyas* sp." are reported (USDA 2003). Interceptions have been associated predominantly with international airline passengers (96%). The pest has been intercepted at three ports of entry in the United States: Honolulu (76%), Los Angeles (13%), and San Francisco (2%). These ports are the first points of entry for airline passengers or cargo coming into the US and do not necessarily represent the intended final destination of infested material. Movement of potential infested material within the US is more fully characterized later in this document. The remaining interceptions (4%) were reported from preclearance in New Zealand. *Epiphyas postvittana* or "*Epiphyas* sp." has been intercepted in association with 9 plant taxa. The majority (57%) listed strawberry (*Fragaria* sp.) as the host.

   International movement of *E. postvittana* has also been noted in Japan where the pest was intercepted 63 times at one port of entry in one year (Takahashi 2002). Nearly 40% of the interceptions were of larvae on New Zealand peppers (Takahashi 2002).

6. **Destination of Infested Material. Rating: Low.** When an actionable pest is intercepted, officers ask for the intended final destination of the conveyance. Cargo or passengers carrying infested materials were destined for two states: Hawaii (74%) and California (26%). We note that California has a climate and hosts that would be suitable for establishment by *E. postvittana*.

7. **Potential Economic Impact. Rating: High.** *E. postvittana* is reported as a pest of economic importance to many ornamental and fruit crops throughout its range (Zhang 1994). According to Geier (Geier and Briese 1981) "Economic damage results from feeding by caterpillars, which may:
   - destroy, stunt or deform young seedlings…
   - spoil the appearance of ornamental plants
   - injure deciduous fruit-tree crops, citrus, and grapes".

   E. postvittana is a difficult to control with sprays because of its leaf-rolling ability, and because there is evidence of resistance due to overuse of sprays (Geier and Briese 1981). Conifers are damaged by needle-tying and chewing (Nuttal 1983). Larvae have been found feeding near apices of Bishop Pine seedlings where they spin needles down against the stem and bore into the main stem from the terminal bud (Winter 1985). "After the first moult they construct typical leaf rolls (nests) by webbing together leaves, a bud and one or more leaves, leaves to a fruit, or by folding and webbing individual mature leaves. During the fruiting season they also make nests among clusters of fruits, damaging the surface and sometimes tunneling into the fruits. During severe outbreaks damage to fruit may be as high as 85%" (Danthanarayana 1975).

In 1992, 70,000 larvae/ha were documented which caused a loss of 4.7t of chardonnay fruit (Bailey et al. 1995). Damage in the 1992-93 Chardonnay season at Coonawarra (southern Australia) cost $2,000/ha (Bailey et al. 1996). Mature larvae are the most difficult stage to control (Lay-Yee et al. 1997). A single larva can destroy about 30 g of mature grapes (Bailey 1997 BAM control options). Damage to apples is in the form of either pinpricks, which are flask-shaped holes about 3 mm deep into the fruit, or entries, which are holes extending deeper than 3 mm into the fruit that leaves some frass and webbing at the surface (van Den Broek 1975). The first generation (in spring) causes the most damage to apples while the second generation damages fruit harvested later in the season (Terauds 1977). Some varieties of apples such as 'Sturmer Pippin' (an early variety), 'Granny Smith' and 'Fuji' (late varieties) can have up to 20% damage (Suckling and Ioriatti 1996), while severe attacks can damage up to 75% of a crop (USDA 1984). Peaches are damaged by feeding that occurs on the shoots and fruit (Lo et al. 1995). Following feeding damage, fruits of many host plants such as grapes are susceptible to secondary damage such as grey mold caused by *Botrytis cinerea* (Nair 1985).

Canada has listed *E. postvittana* as a noxious pest, and the presence of the pest would prevent export of any infested commodity (Danthanarayana et al. 1995). In New Zealand, the recommended economic threshold is six or more larvae per 30 m row of fruit crops, however if the crop is intended for export, control is recommended if only one larva is found (Charles et al. 1987).

8. **Establishment Potential. Rating: Medium.** No occurrences of *E. postvittana* have been reported in the wild in the US. However, this species has a broad host range and is likely to find suitable climatic conditions in much of the US. The species may not yet be established in the US because of its apparently low frequency of arrival into a small number of ports.

   For a more detailed description of the biology of *E. postvittana*, see Appendix D.

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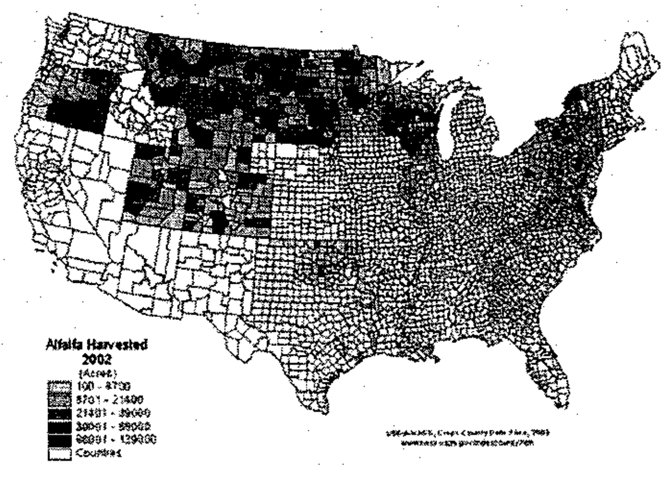
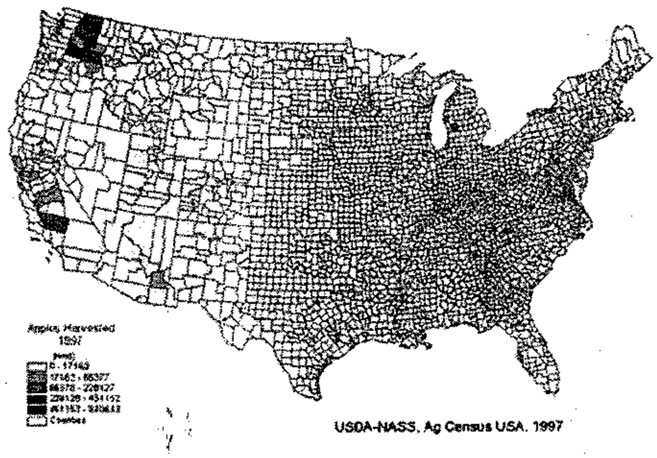
Appendix A. Comparison of climate zones. To determine the potential distribution of a quarantine pest in the US, we first collected information about the worldwide geographic distribution of the species (CAB 2003). We then identified which biomes (i.e., habitat types), as defined by the World Wildlife 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.

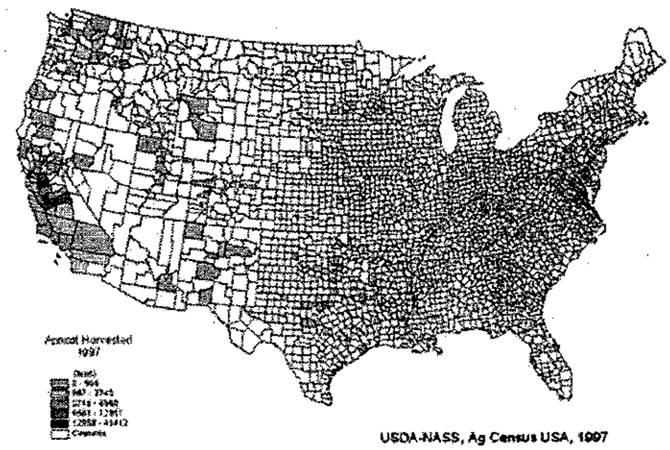
Appendix B. Commercial production of hosts of *Epiphyas postvittana* in the continental US.



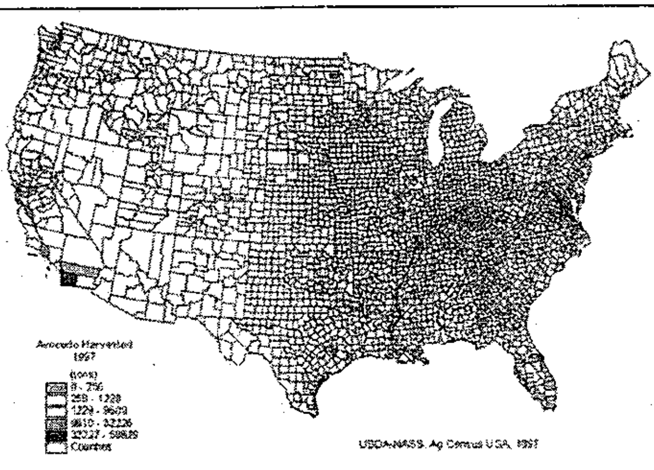
Map 1. Alfalfa (*Medicago sativa*)



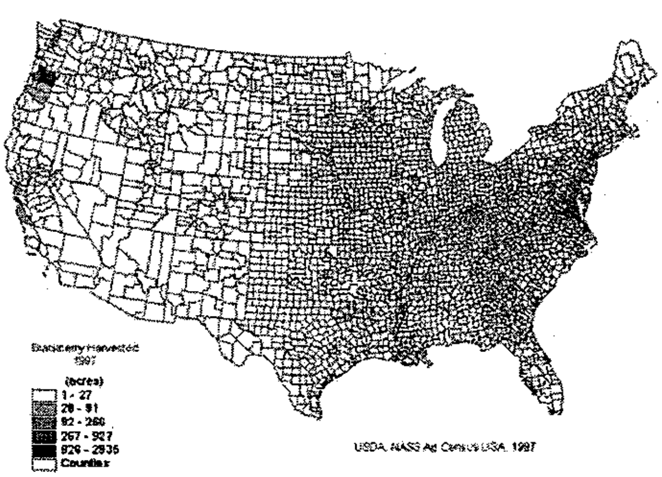
Map 2. Apple (*Malus domestica*)



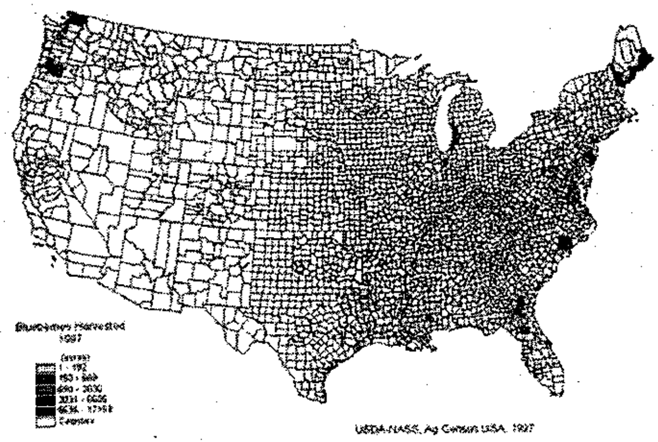
Map 3. Apricot (*Prunus armeniaca*)



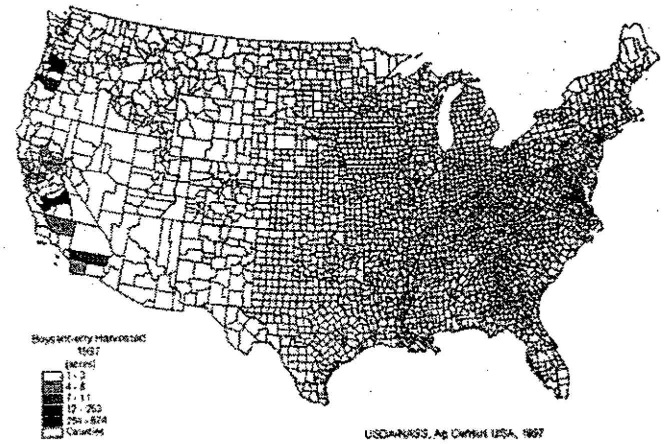
Map 4. Avocado (*Persea americana*)



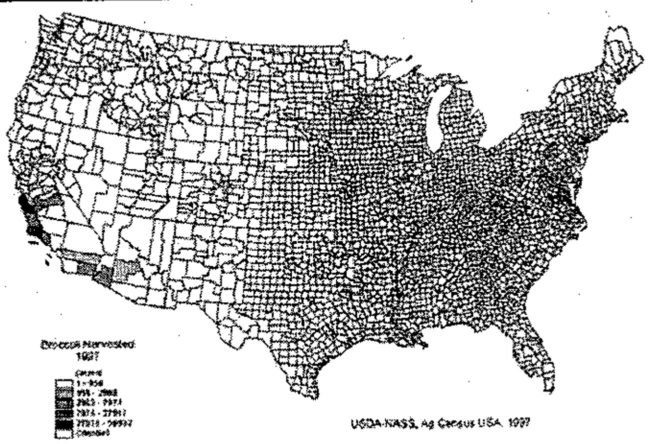
Map 5. Blackberry (*Rubus* spp.)



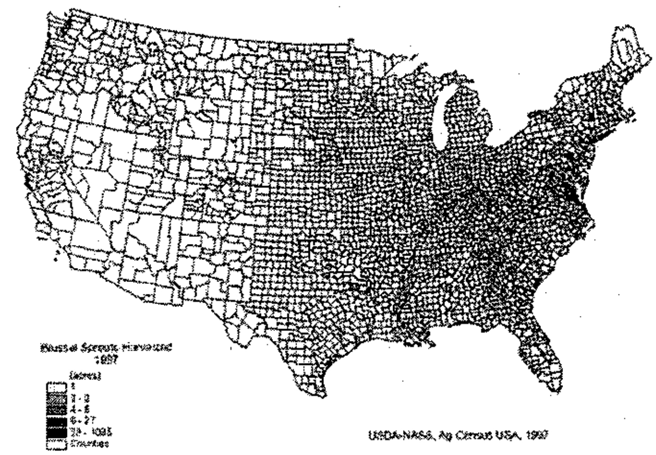
Map 6. Blueberry (*Vaccinium* spp.)



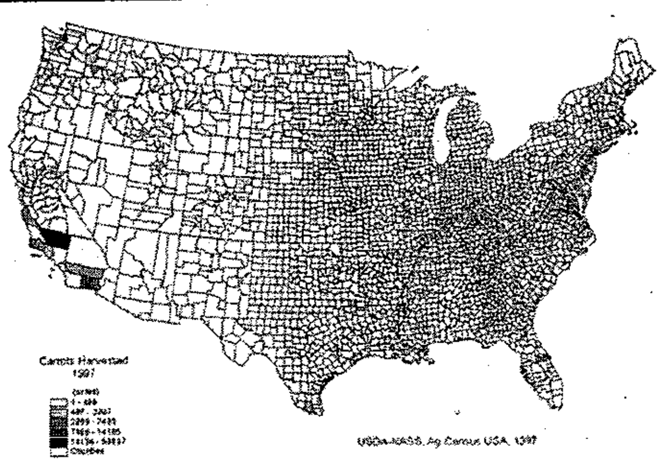
Map 7. Boysenberry (*Rubus* spp.)



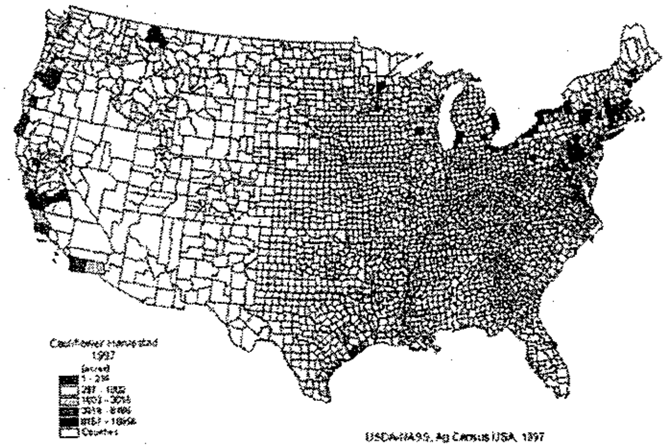
Map 8. Broccoli (*Brassica oleracea* var. *botrytis*)



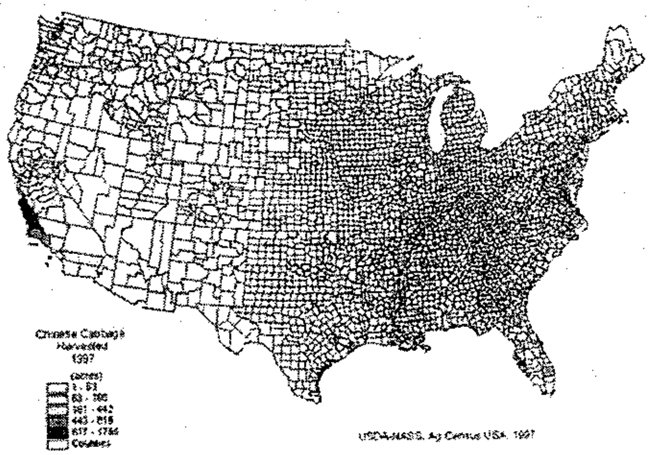
Map 9. Brussels sprouts (*Brassica oleracea* var. *gemmifera*)



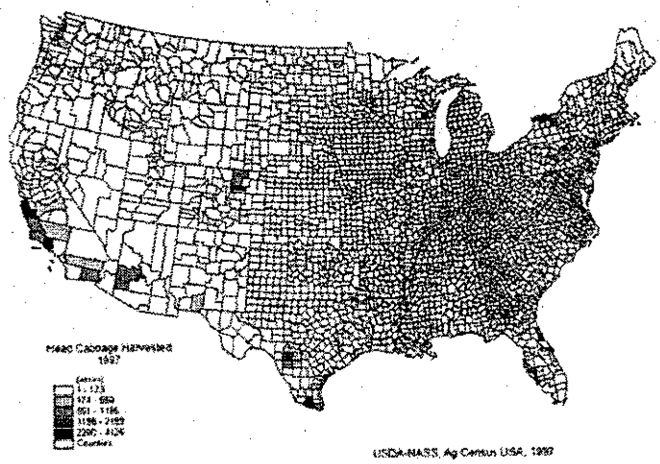
Map 10. Carrot (*Dacus carota* ssp. *sativus*)



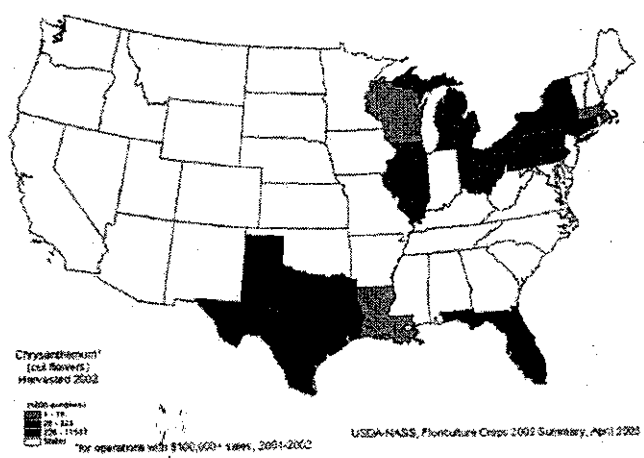
Map 11. Cauliflower (*Brassica oleracea* var. *botrytis*)



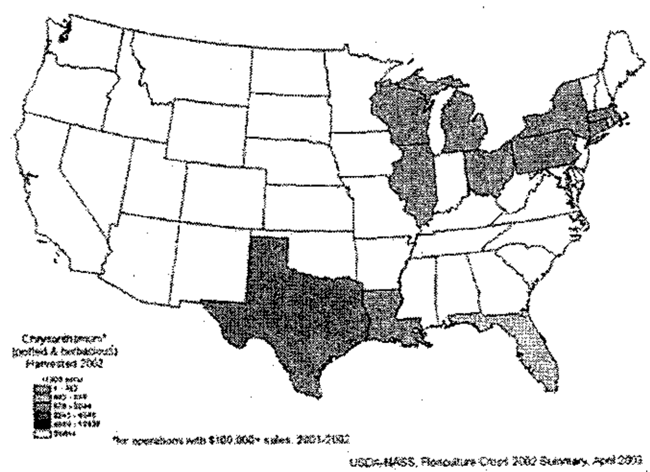
Map 12. Cabbage; Chinese (*Brassica chinensis*)



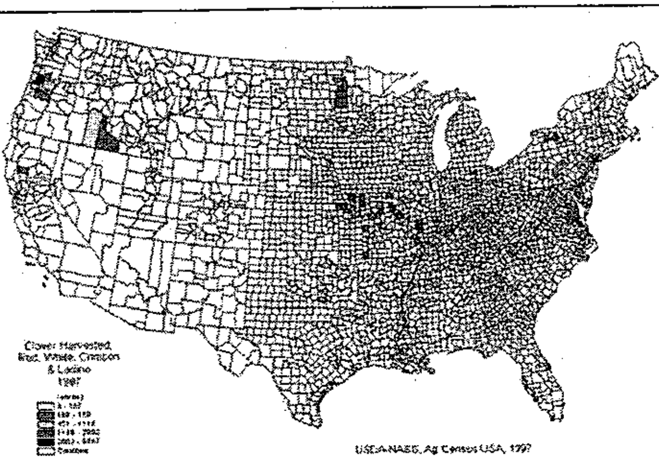
Map 13. Cabbage; head (*Brassica oleracea*)



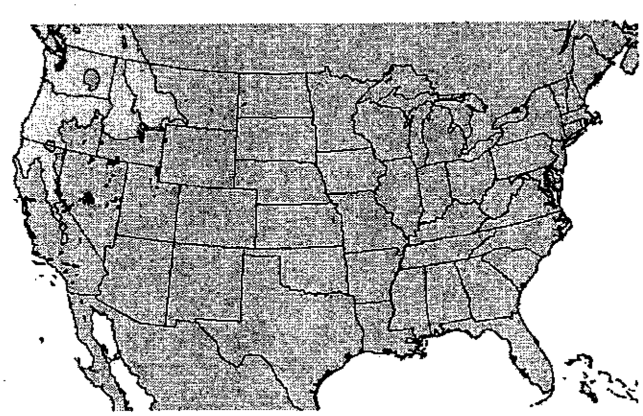
Map 14. Chrysanthemum; cut (*Chrysanthemum* spp.)



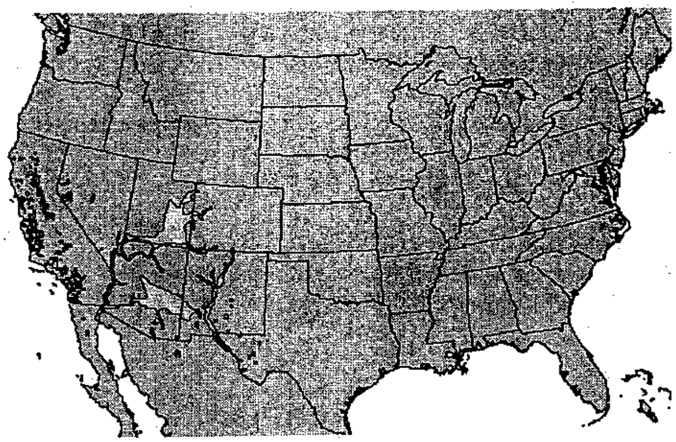
Map 15. Chrysanthemum; potted (*Chrysanthemum* spp.)



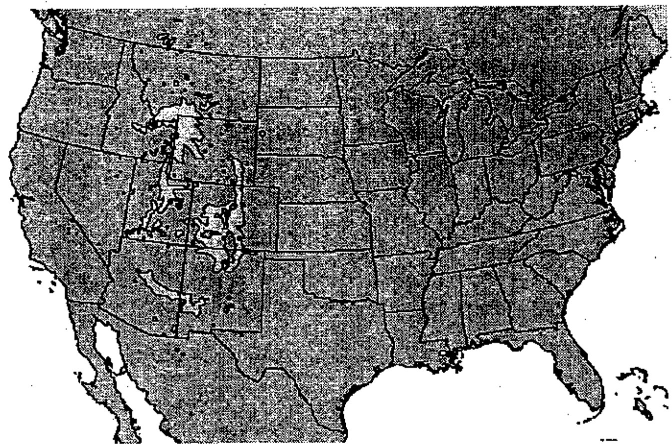
Map 16. Clover (*Trifolium* spp.)



Map 17. Cottonwood; black (*Populus trichocarpa*)

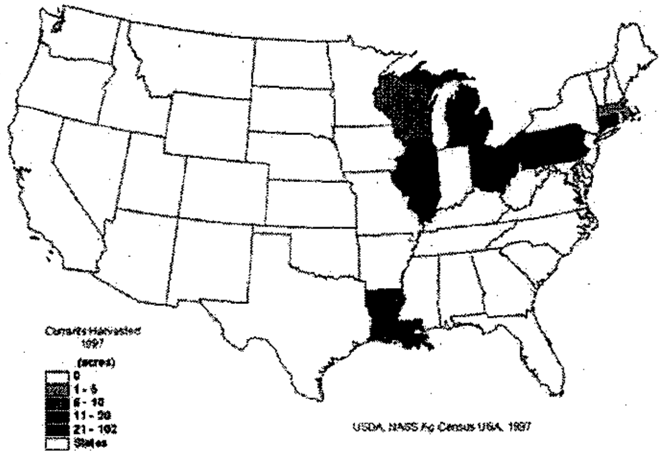


Map 18. Cottonwood-fremont (*Populus fremontii*)

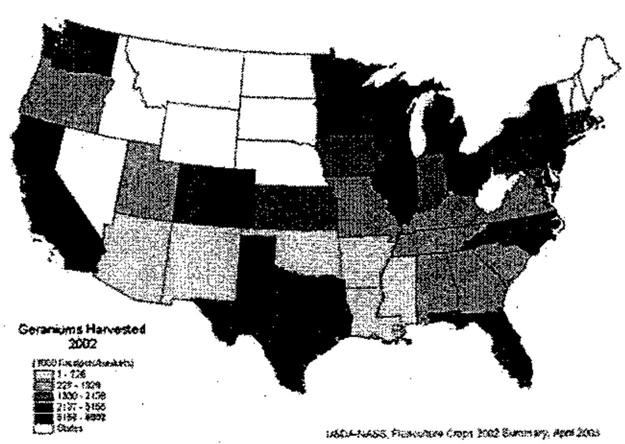


Map 19. Cottonwood-narrowleaf (*Populus angustifolia*)

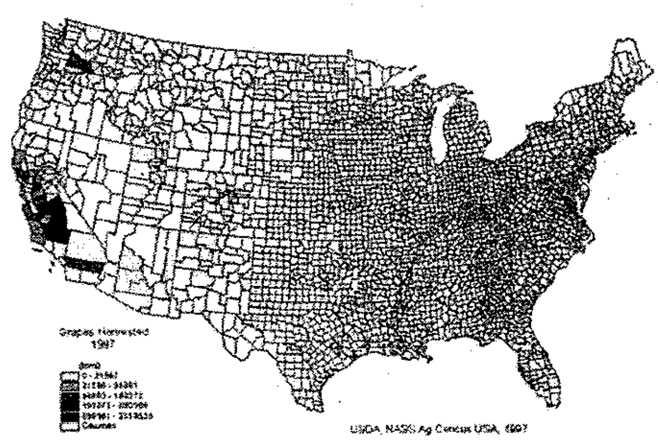
Map 20. Cottonwood; swamp (*Populus heterophylla*)



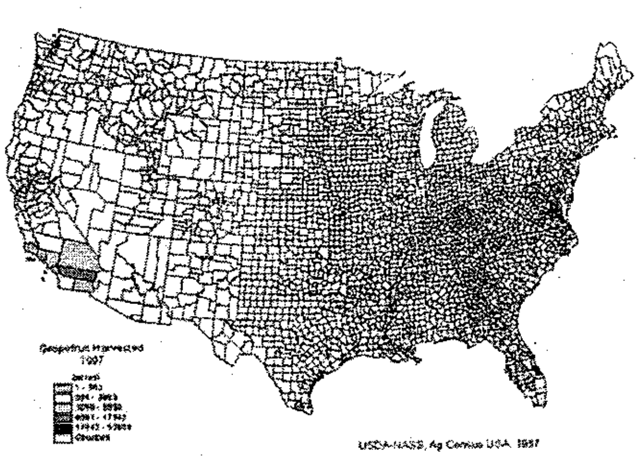
Map 21. Currant (*Ribes* spp.)



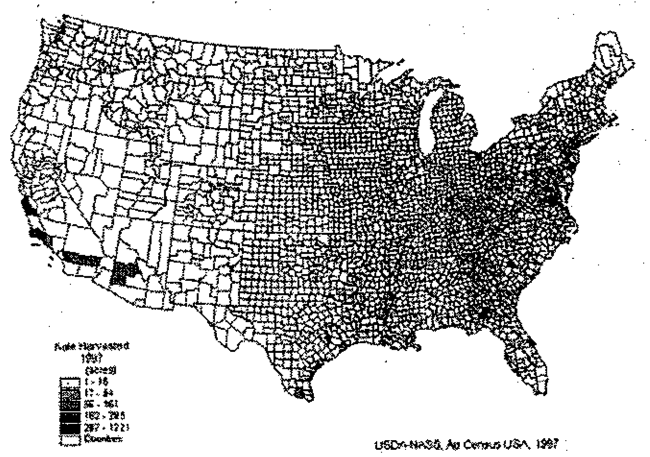
Map 22. Geranium (*Pelargonium* spp.)



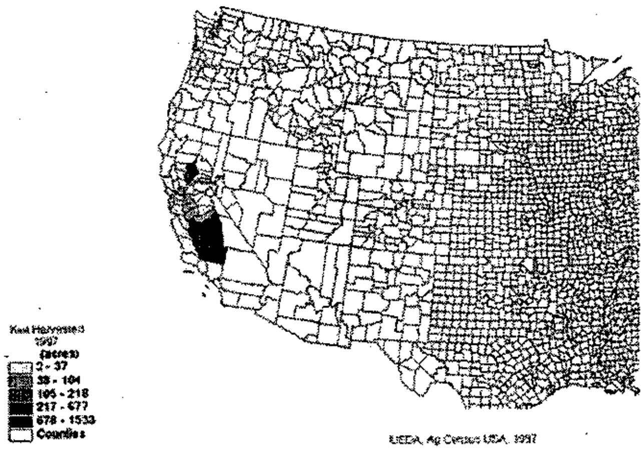
Map 23. Grape (*Vitis* spp.)



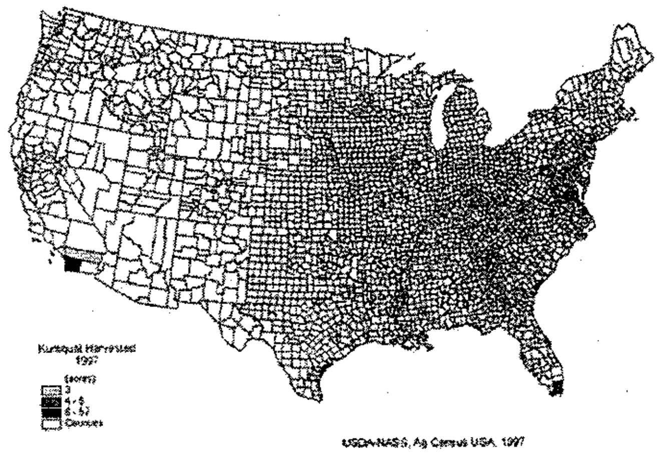
Map 24. Grapefruit (*Citrus paradiss* Mac. Fad.)



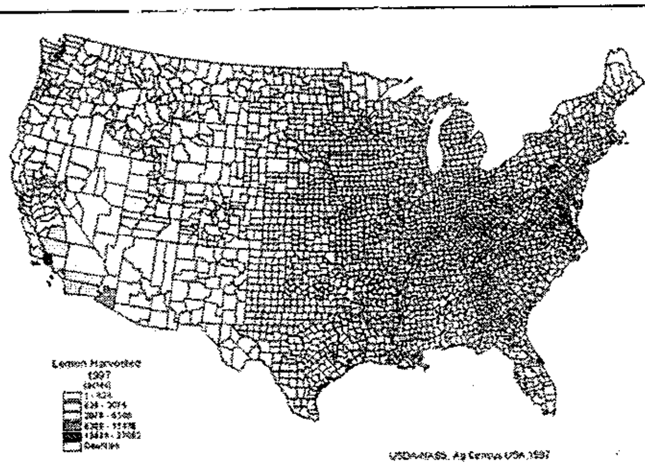
Map 25. Kale (*Brassica alboglabra* L.H. Bailey)



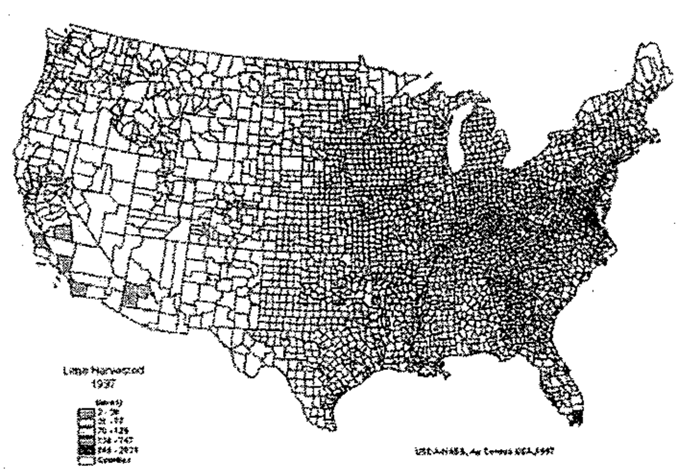
Map 26.Kiwifruit (*Actinidia chinensis*)



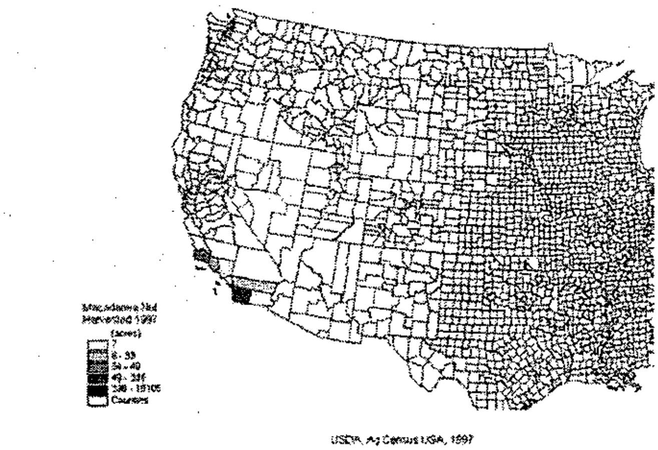
Map 27. Kumquat (*Fortunella* spp.)



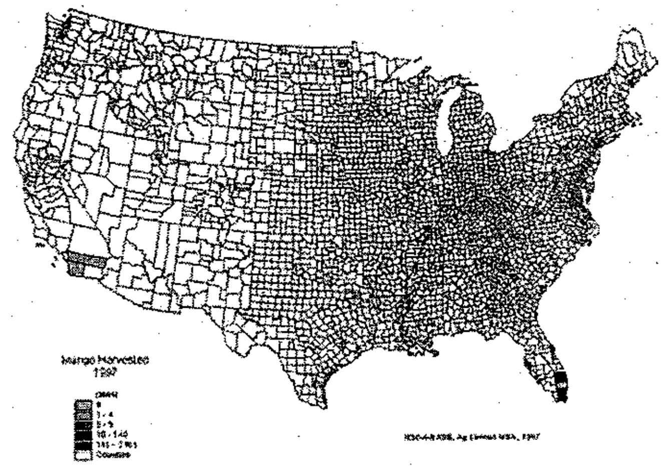
Map 28. Lemon (*Citrus limon*)



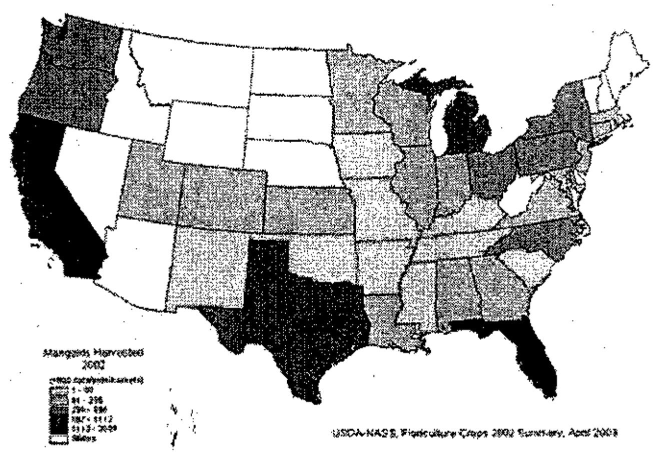
Map 29. Lime (*Citrus aurantfolia*)



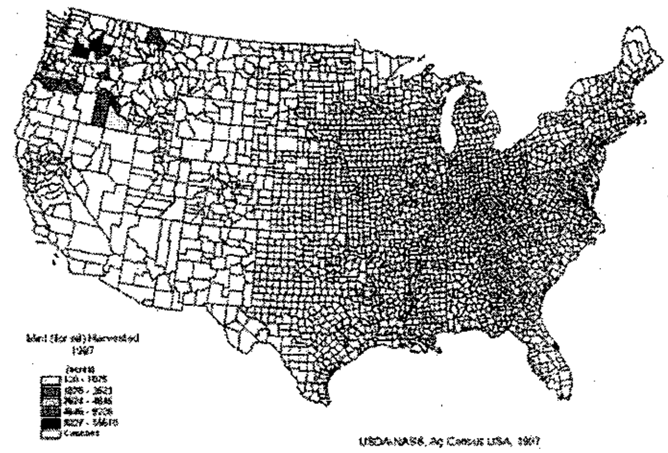
Map 30. Macadamia Nut (*Macadamia ternifolia*)



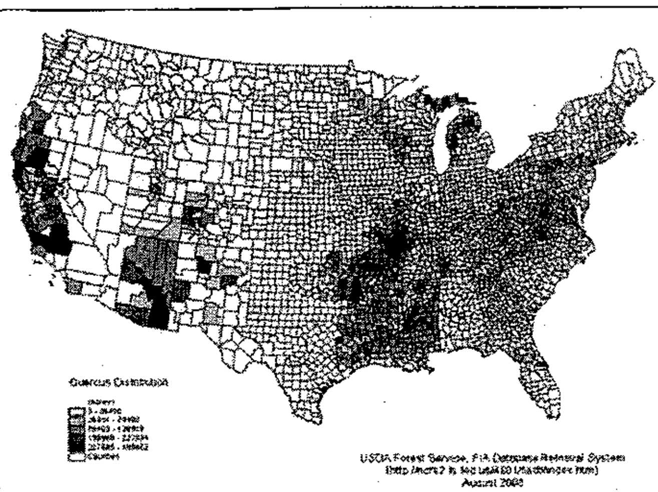
Map 31. Mango (*Mangifera indica*)



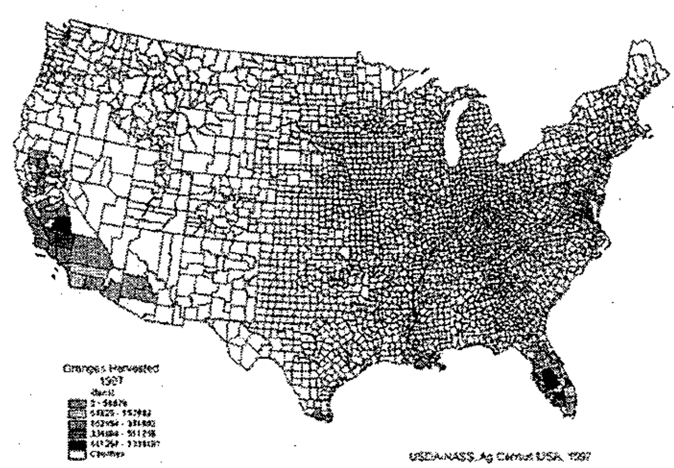
Map 32. Marigold (*Calendula* spp.)



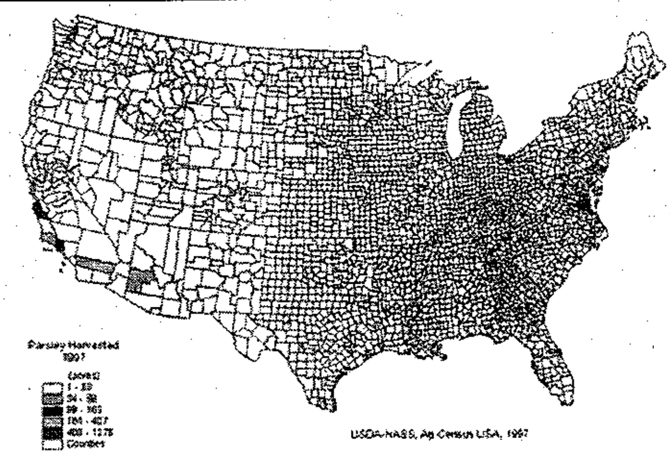
Map 33.Mint; for oil (*Mentha* spp.)



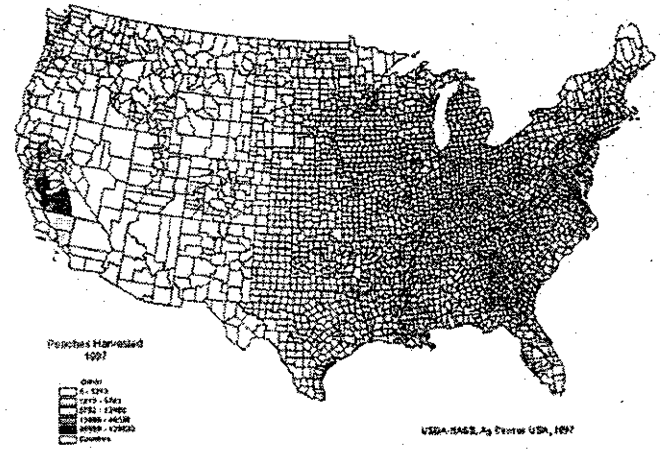
Map 34. Oak (*Quercus* spp.)



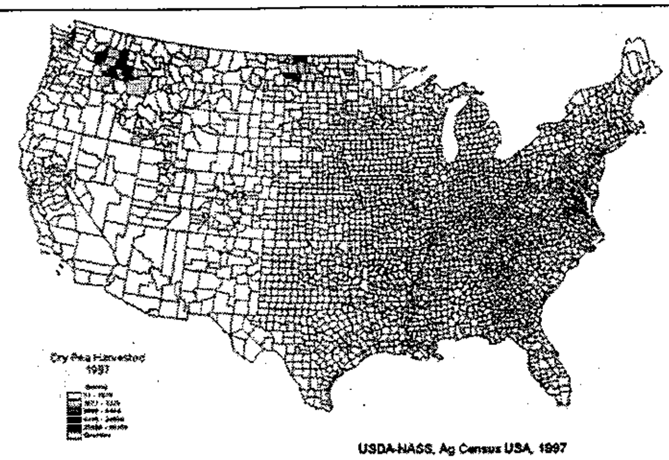
Map 35.Orange (*Citrus* spp.)



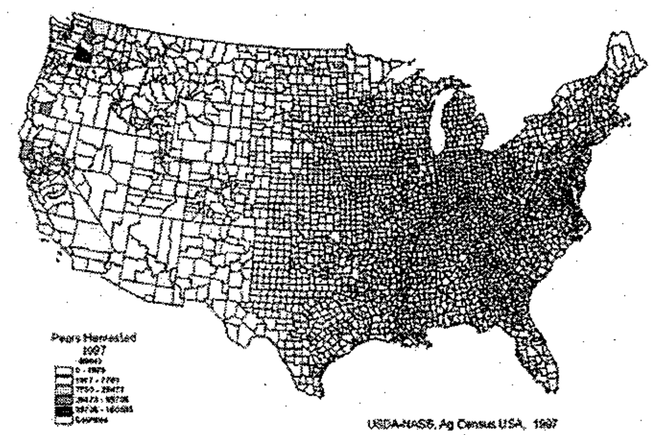
Map 36. Parsley (*Petroselinum* spp.)



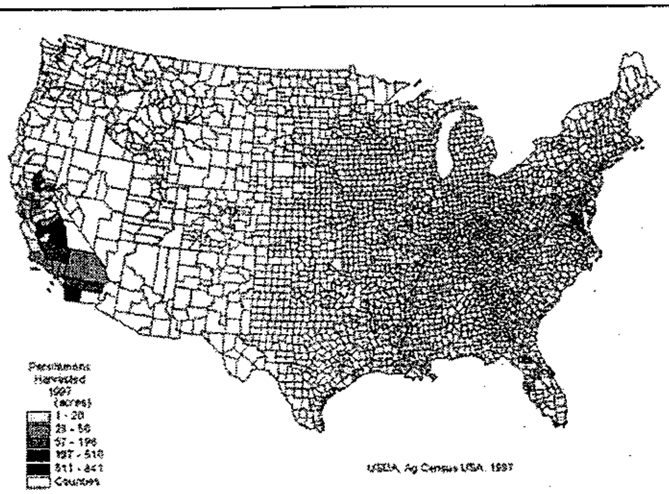
Map 37. Peach (*Prunus persica*)



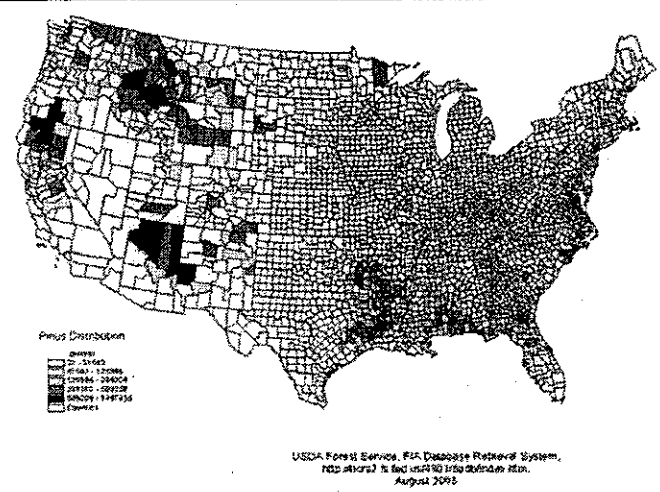
Map 38. Pea; dry edible (*Lathyrus*)



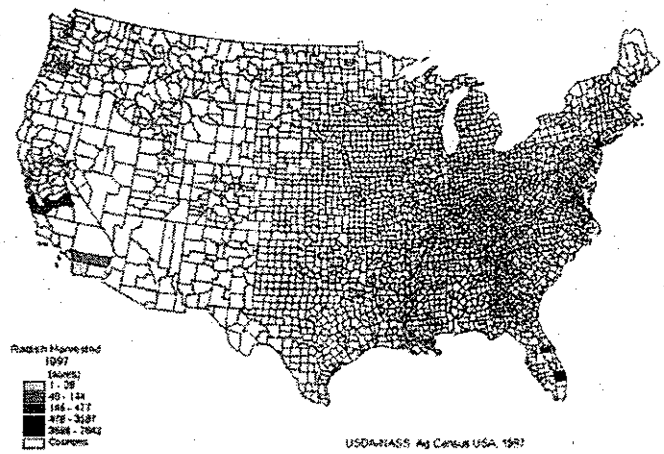
Map 39. Pear (*Pyrus communis*)



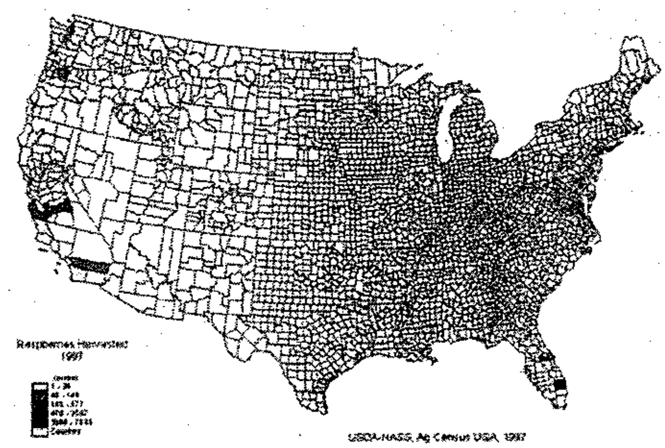
Map 40. Persimmons (*Diospyros* spp.)



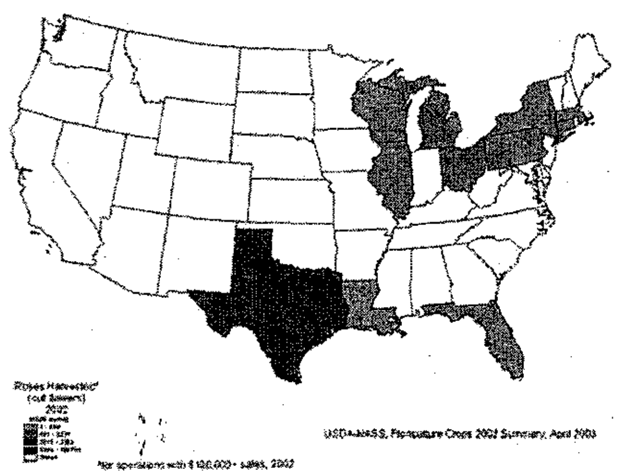
Map 41. Pine (*Pinus* spp.)



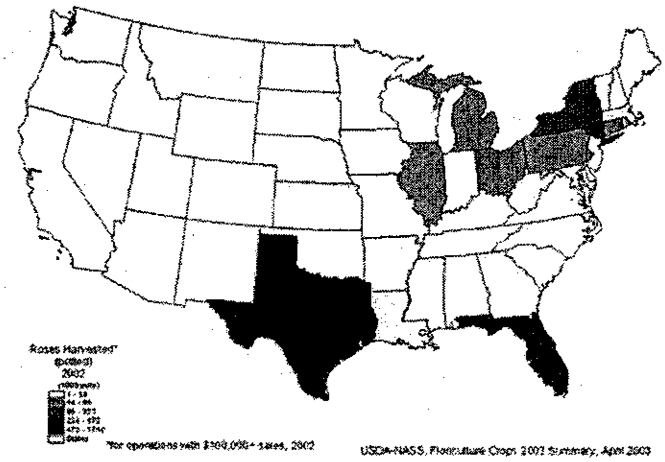
Map 42. Radish (*Raphanus* spp.)



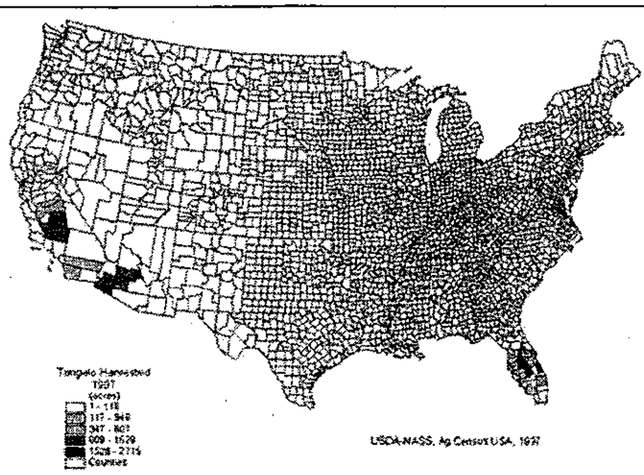
Map 43. Raspberry (*Rubus* spp.)



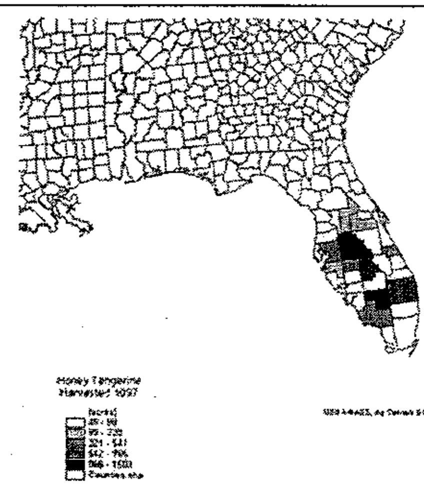
Map 44. Rose; cut (*Rosa* spp.)



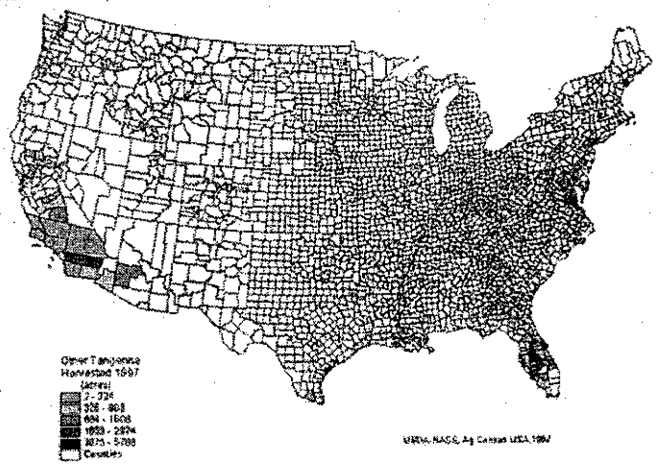
Map 45. Rose; potted (*Rosa* spp.)



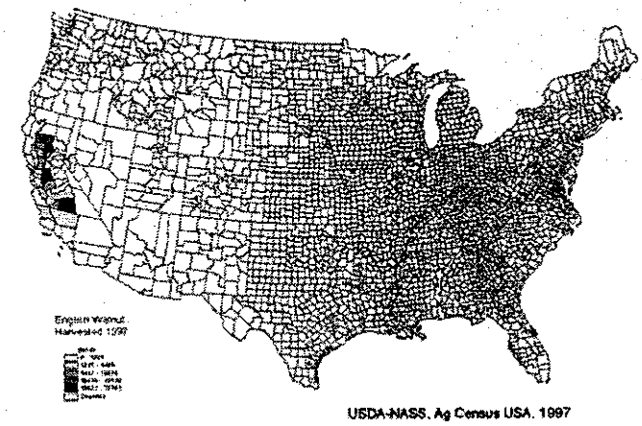
Map 46. Tangelo (*Citrus tangelo*)



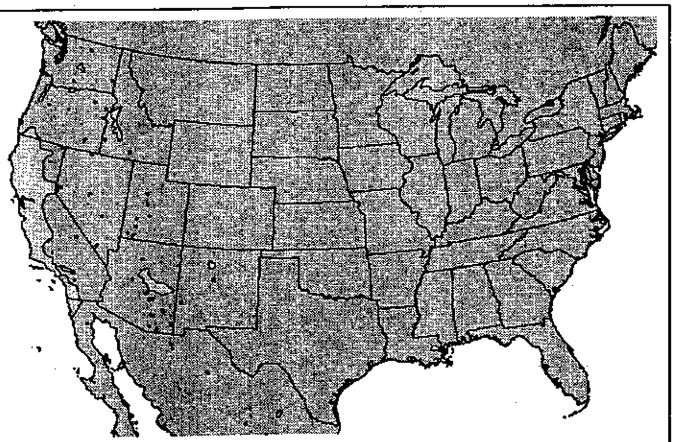
Map 47. Tangerine; honey (*Citrus reticulata*)



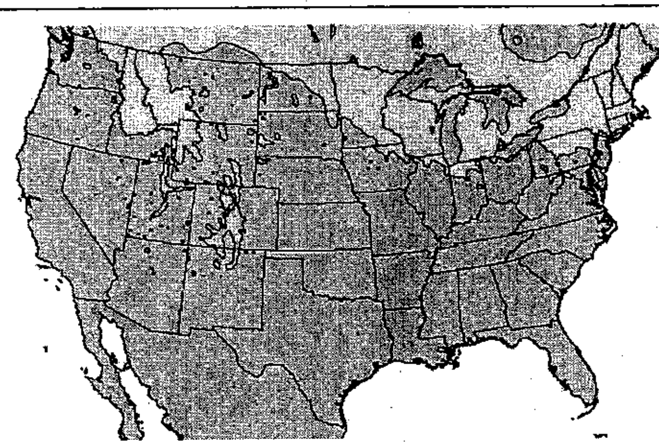
Map 48. Tangerine; other (*Citrus reticulata*)



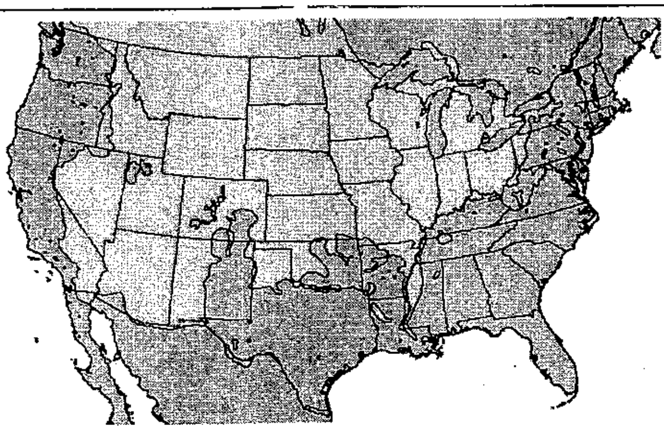
Map 49. Walnut; English (*Juglans regia*)



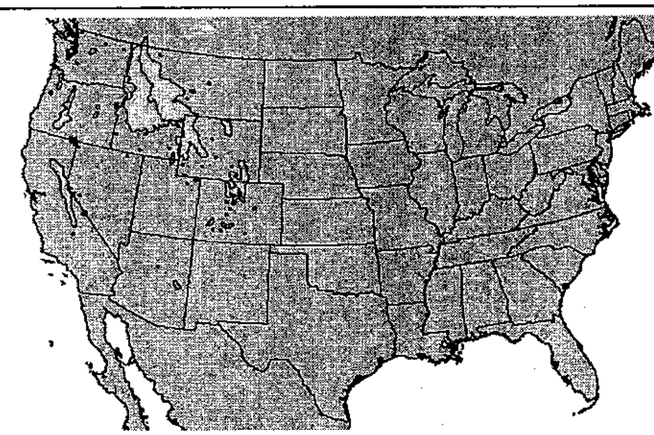
Map 50. Willow; arroyo (*Salix lasiolepis*)



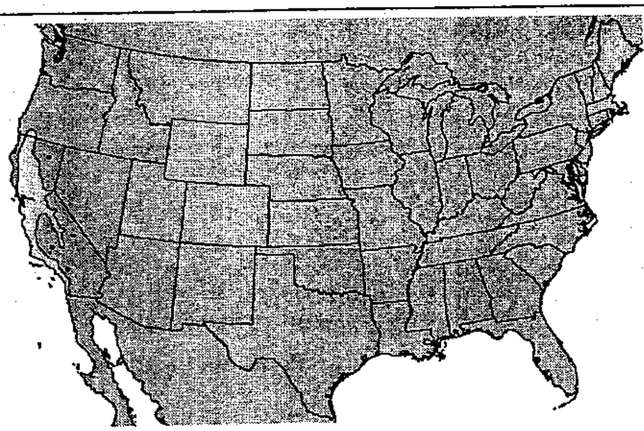
Map 51. Willow; Bebb (*Salix bebbiana*)



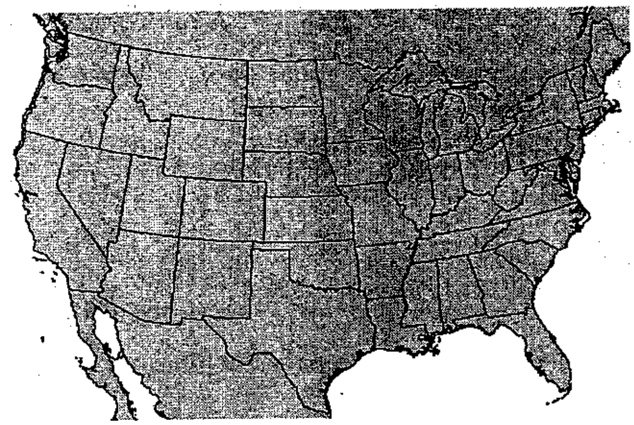
Map 52. Willow; coyote (*Salix exigua*)



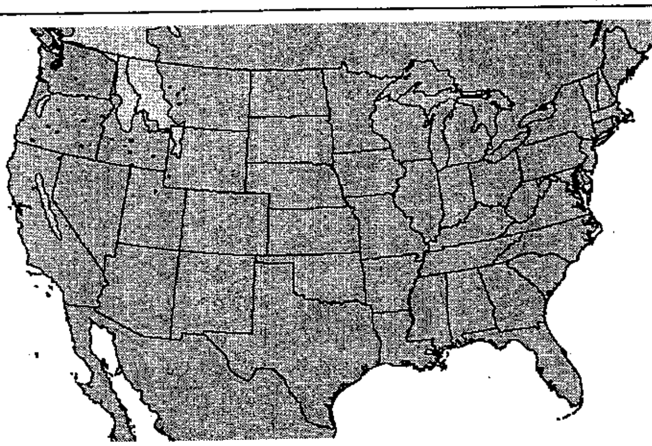
Map 53. Willow; Geyer (*Salix geyeriana*)



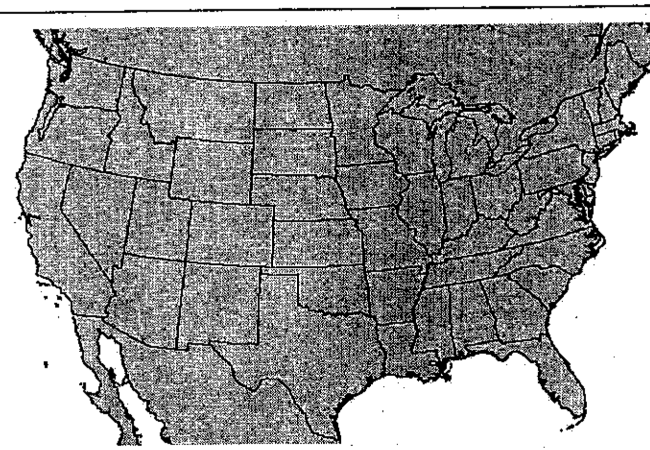
Map 54. Willow; Hinds (*Salix hindsiana*)



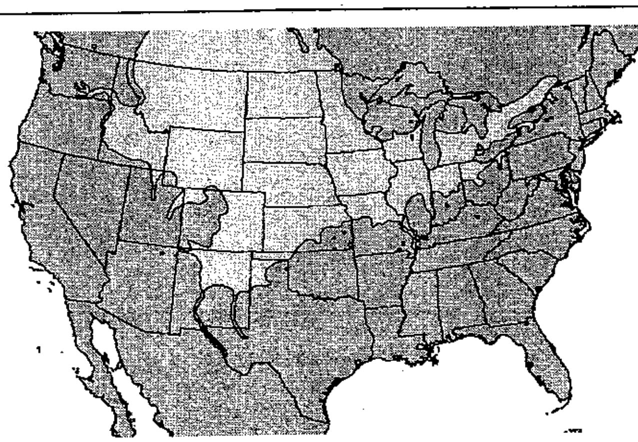
Map 55. Willow; Hooker (*Salix hookeriana*)



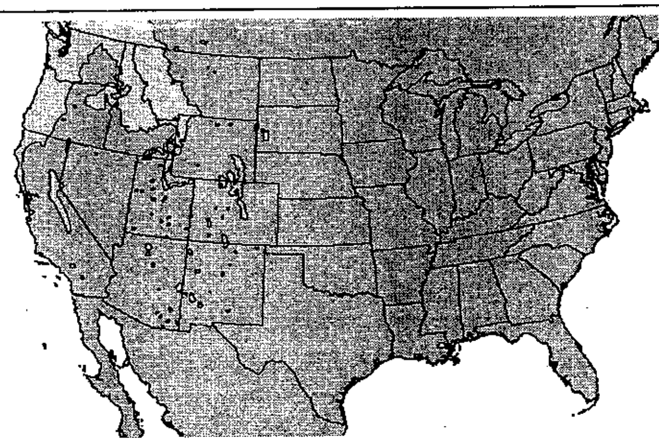
Map 56. Willow; Mackenzie (*Salix mackenzieana*)



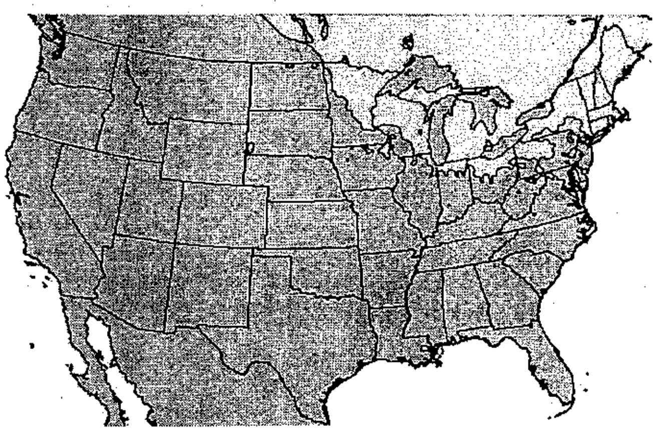
Map 57. Willow; northwest (*Salix sessilifolia*)



Map 58. Willow; peachleaf (*Salix amygdaloides*)



Map 59. Willow; Scouler (*Salix scouleriana*)



Map 60. Willow; shining (*Salix lucida*)

Map 61. Willow; Sitka (*Salix sitchensis*)

Appendix C. Taxonomy of *Epiphyas postvittana* (Walker) and related Tortricidae (prepared by M. DaCosta)

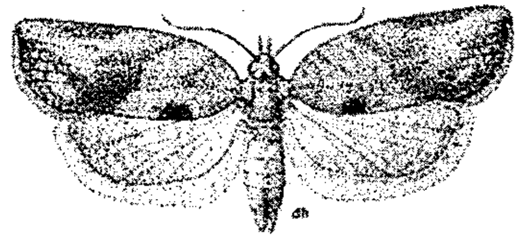


Figure C1. Sketch of *Epiphyas postvittana* adult
[image from http://www.hortnet.co.nz/publications/hortfacts/images/ hf401003.gif]

Synonyms (provided by John Brown, National Museum of Natural History, personal communication)

At the generic level:
Epiphyas Turner 1927, Pap. Roy. Soc. Tasmania 1926: 125. Type species: *Epiphyas eucyrta* Turner, 1926.

- *Austrotortrix* Bradley, 1956, Bull. Entomol. Res. 47: 101. Type species: *Teras postvittana* Walker, 1863.
- *Austerotortrix* Razowski, 1977, Journal: 00. [misspelling of *Austrotrix*]

At the species level:
postvittana Walker, 1863 (*Teras*), List Spec. Lepid. Ins. Colln. Brit. Mus. 28: 297. TL: Australia (Sydney). HT (♀): BMNH.

- *scitulana* Walker, 1863 (*Teras*), List. Spec. Lepid. Ins. Colln.. Brit. Mus. 28: 298. TL: Australia (Sydney). HT (♂): BMNH.
- *basialbana* Walker, 1863 (*Teras*), List Spec. Lepid. Ins. Colln. Brit. Mus. 28: 299. TL: Australia. HT (♂): BMNH.
- *secretana* Walker, 1863 (*Teras*), List Spec. Lepid. Ins. Colln. Brit. Mus. 28: 300. TL: Australia. HT (♀): BMNH.
- *consociana* Walker, 1863 (*Pandemis*), List Spec. Lepid. Ins. Colln. Brit. Mus. 28: 311. TL: Australia (Sydney). HT (♀): BMNH.
- *reversana* Walker, 1863 (*Dichelia*), List Spec. Lepid. Ins. Colln. Brit. Mus. 28: 321. TL: Australia (Sydney). HT (♂): BMNH.
- *foedana* Walker, 1863 (*Dichelia*), List Spec. Lepid. Ins. Colln. Brit. Mus. 28: 321. TL: Australia. HT (♀): BMNH.
- *retractana* Walker, 1863 (*Dichelia*), List Spec. Lepid. Ins. Colln. Brit. Mus. 28: 322. TL: Australia. HT (♀): BMNH.
- *vicariana* Walker, 1869 (*Dichelia*), Char. Undescr. Heter.: 82. TL: Australia. HT: NMVM.
- *stipularis* Meyrick, 1910 (*Totrix*), Proc. Linnean Soc. N.S. Wales 35: 226. TL: Australia (Victoria, Murtoa). HT (♂): Lyell Collection.

- *pyrrhula* Meyrick, 1910 (*Tortrix*), Proc. Linnean Soc. N.S. Wales 35: 226. TL: Australia (South Australia, Port Lincoln). LT: BMNH.
- *oenopa* Meyrick, 1910 (*Tortrix*), Proc. Linnean Soc. N.S. Wales 35: 230. TL: Australia (Victoria). HT (♂): Lyell Collection.
- *dissipata* Meyrick, 1922 (*Tortrix*), Exotic Microlepid. 2: 496. TL: Australia (Yallingup). HT: BMNH.
- *phaeosticha* Turner, 1939 (*Tortrix*), Pap. Proc.. Roy. Soc. Tasmania 1938: 76. TL: Tasmania. HT: Unknown.
- *vicaureana* Bradley, 1957 (*Dichelia*), Bull. Entomol. Res. 47: 103. [misspelling of *vicariana*].

Male 16-21 mm, female 17-25 mm. Sexual dimorphism pronounced; male usually smaller, antenna weakly dentate-ciliate, length of cilia approximately equal to width of flagellum, basal half of forewing usually sharply demarcated, well-developed costal fold from base to about two-fifths; antenna of female minutely ciliate, forewing longer, apex produced (Fig C2).

Diagnosis of *Epiphyas postvittana* [Description from Bradley et al (1973)]

Male *E. postvittana* (Walker) is usually distinguished by the abrupt division of the forewing medially into a pale basal area and darker apical area, and the female by its large size and relatively elongate forewing, often with greatly reduced markings (Fig. C2).

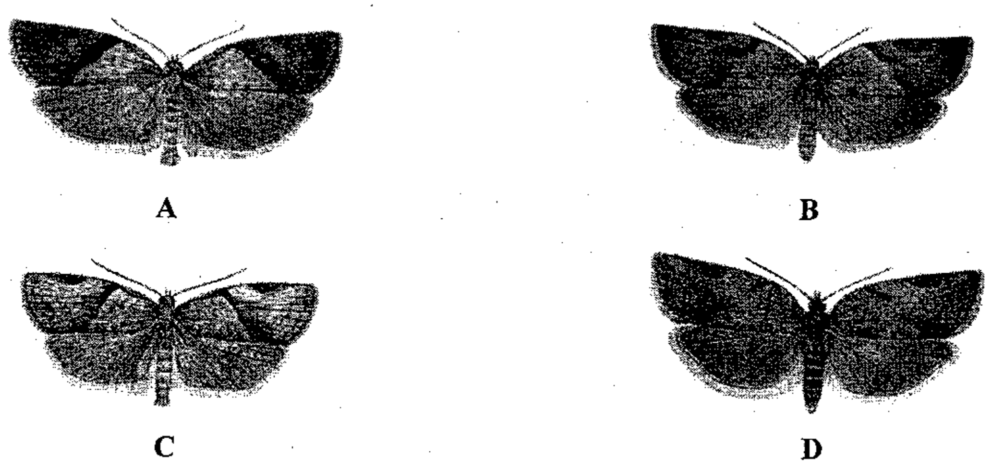


Figure C2. Dorsal views of *Epiphyas postvittana* (Walker), A-male, B-female, C-male, D-female [Reproduced from Bradley et al. (1979)]

Description

***Head*:** No verbal description available. But, see Fig. C3.

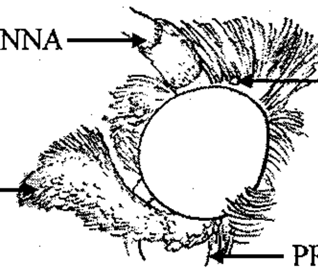


Figure C3. Lateral view of head of *Epiphyas postvittana* (Walker)-male [Reproduced from from Zimmerman (1978)]

***Female body*:** [Description from Hampson (1863)] Palpi extends forward horizontally, as long as the breadth of the head; second joint fringed above; third conical, very minute, not more than one-sixth of the length of the second. Abdomen yellowish ash-colored.

***Male wings*:** As in Figure C2. [Description from Bradley et al (1973)] Basal half of forewing light buff or pale yellow, contrasting strongly with the dark brown and rusty red-brown coloration of the distal half, the demarcation often emphasized by the deeper coloration of the oblique, narrow median fascia, the inner edge of which is sharply defined and usually straight, but sometimes is slightly wavy at the middle; pre-apical spot obscure, its inner margin usually defined by rusty red-brown ground coloration separating it from the median fascia. Hindwing gray.

***Female wings*:** As in Figure C2. [Description from Bradley et al (1973)] General coloration of the forewing more uniform, with less contrast between the basal and distal halves; median fascia usually reduced.

***Wing variation*:** Figure C4 describes variation that may be encountered in wing patterns and provides explanation of morphological terminology. [Description from Bradley et al (1973)] *Epiphyas postvittana* (Walker) is extremely variable with numerous recurring forms. In strongly marked forms of the male the distal half of the forewing may vary from reddish brown to blackish, often with purplish mottling; the contrasting pale basal half may be sparsely speckled with black. Lightly marked forms resembling the female in appearance occur; an extreme form in which the usually dark outer half of the forewing is light and the pre-apical spot discernible is uncommon (Fig. C2-C). Only minor variation is found in the female; often the forewing is irrorate with black in both the basal and distal halves of the wing (Fig. C2-D).

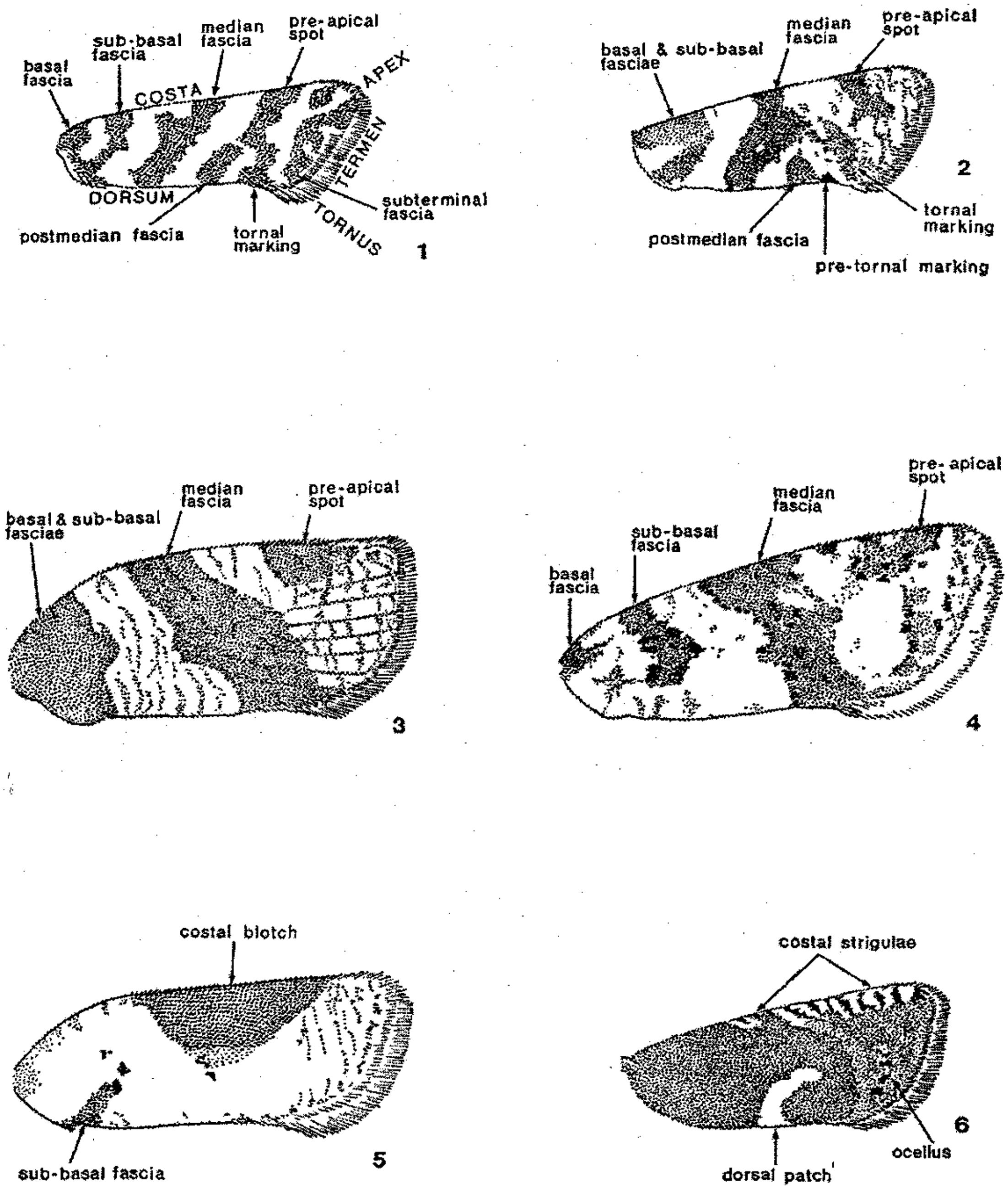


Figure. C4. Variation in wing patterns of Tortricoid moths
[Reproduced from Bradley et al. (1979)]

***Venation*:** No verbal description available, but see Figure C5.

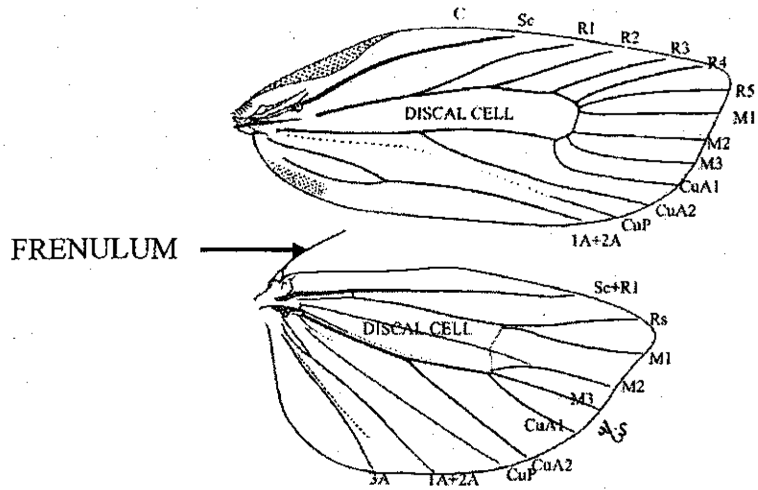
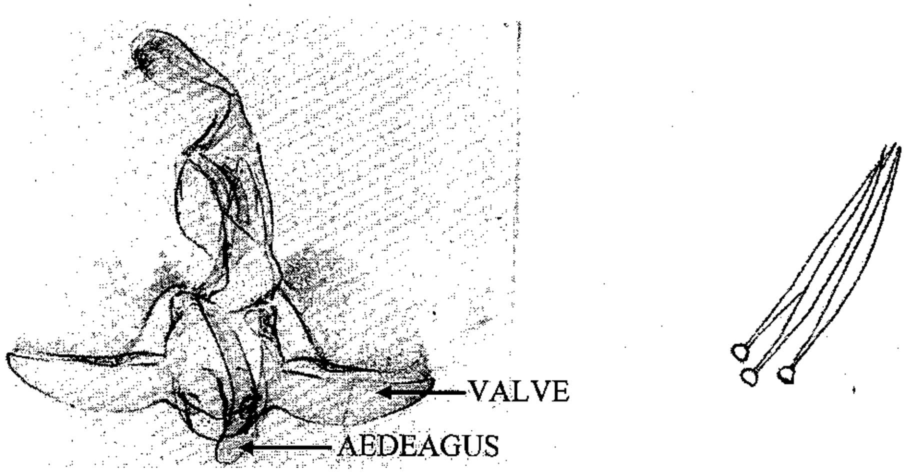


Figure C5. Wing venation of *Epiphyas postvittana* (Walker)-male. Veins: A-anal; C-Costa, Cu-Cubitus (CuA1-1st anterior cubitus; CuA2-2nd anterior cubitus; CuP-posterior cubitus); M-Media, R-Radius, Sc-Subcosta.
[Reproduced from Zimmerman (1978)]

***Male genitalia*:** [Description from Zimmerman (1978)] The internal sac of the aedeagus bears two to four long, narrow, flattened cornuti. These are deciduous and may be missing from mated specimens. When the cornuti are shed the points of articulation can still be seen (Fig C6)

Terminology follows Klots (1970).



A **B**

Figure C6. Ventral view of male genitalia of *Epiphyas postvittana* (Walker): A-genital capsule; B-cornuti [Reproduced from Zimmerman (1978)]

Female genitalia: No verbal description, but see Fig. C7.

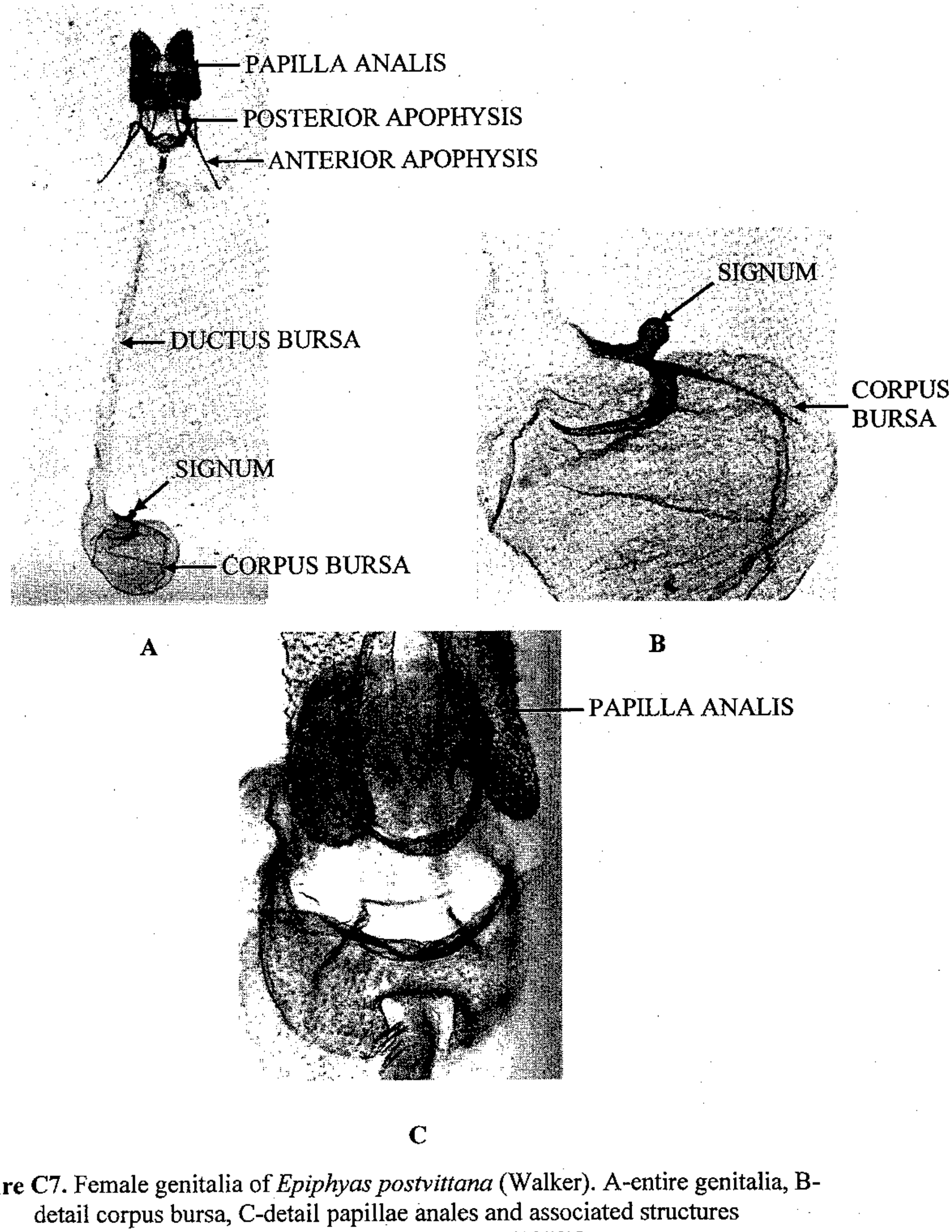


Figure C7. Female genitalia of *Epiphyas postvittana* (Walker). A-entire genitalia, B-detail corpus bursa, C-detail papillae anales and associated structures [Reproduced from Zimmerman (1978)].

Larvae: No verbal description, but see Fig.C8.

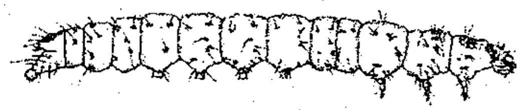


Figure C8. Lateral view of *Epiphyas postvittana* (Walker) larva
[Reproduced from Scott (1984)]

Pupae: No verbal description, but see Fig C9. Length 10.5mm

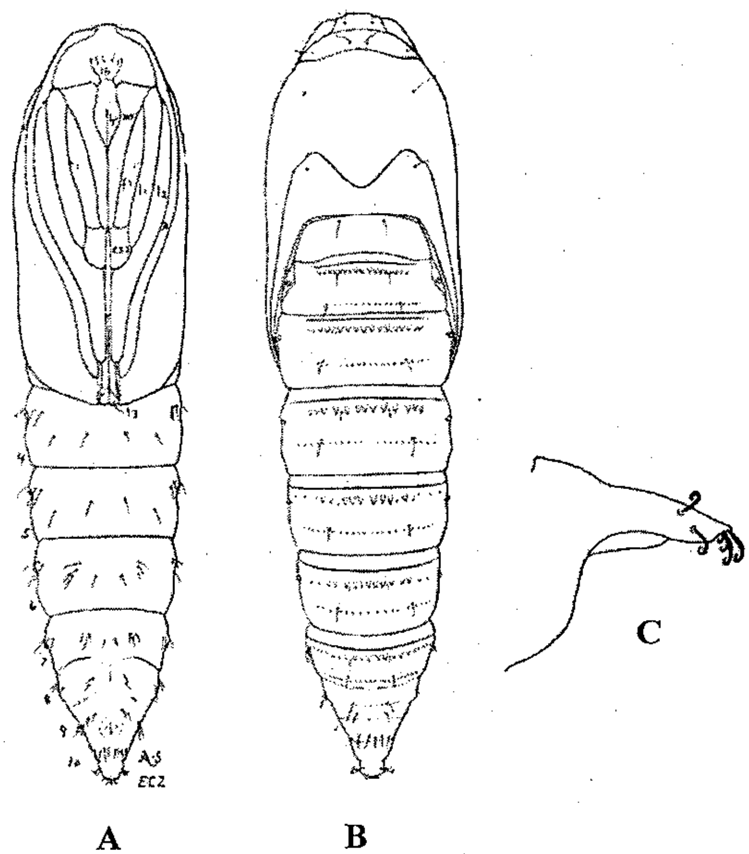


Figure C9. Pupa of *Epiphyas postvittana* (Walker): A-ventral view , B-dorsal view , C-detail lateral view left side cauda of pupa. In A: cx2-mesocoxa; fl-profemora; lb-labrum; lp-labial palpus, l1, l2, l3-legs; mx-galea of maxilla (probscis); W2-hindwing [Reproduced from Zimmerman (1978)].

Similar species:
A key to the larvae and pupae of *Epiphyas postvittana* (Walker) and *Amorbia emigratella* Busck is provided in Zimmerman (Zimmerman 1978).

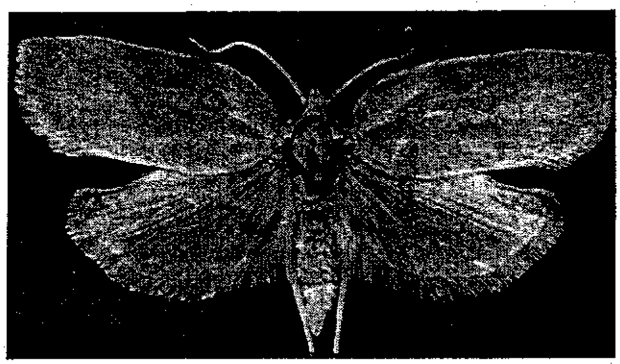


Figure C10. *Amorbia emigratella* Busck
[Reproduced from Zimmerman (1978)]

[Description from Zimmerman (1978)] *Epiphyas postvittana* can be distinguished from *Amorbia emigratella* by:

1) The presence of ocelli which are absent in *A. emigratella.*
2) The undersides of the hindwings of *E. postvittana* are conspicuously spotted whereas those of *A. emigratella* are not.
3) *A. emigratella* has a conspicuous median pit in the second abdominal tergite near the base, while *E. postvittana* does not.
4) The larvae of both are green but there is a black line on each lateral margin of *A. emigratella* larvae which is absent in the larvae of *E. postvittana.*

Head: See Fig C11.

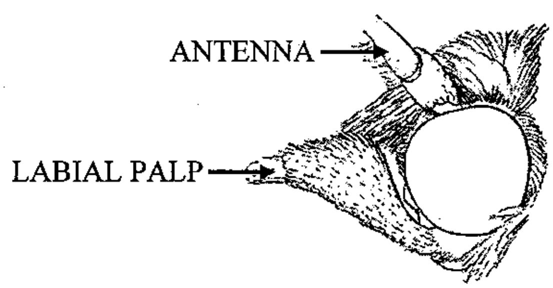


Figure C11. Lateral view of head of *Amorbia emitratella* Busck-male
[Reproduced from Zimmerman (1978)]

Venation: As in Fig. C12.

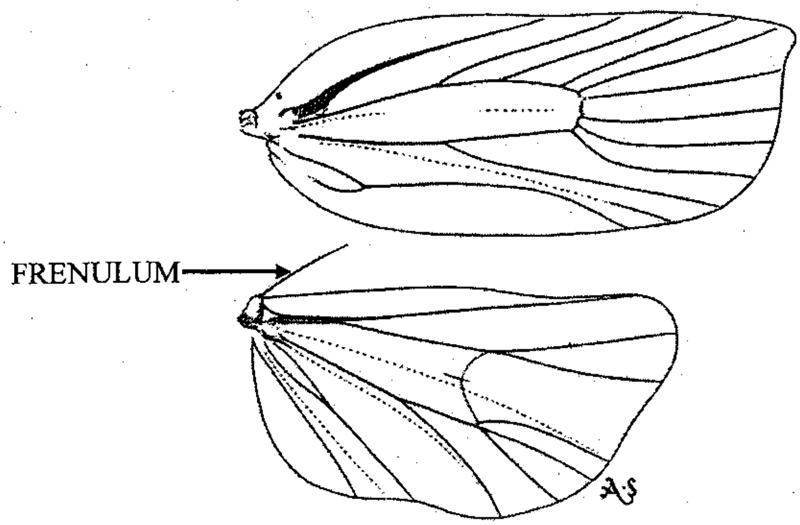


Figure C12. Venation of *Amorbia emigratella* Busck –male. [Reproduced from Zimmerman (1978)].

Male genitalia: As in Fig. C13.

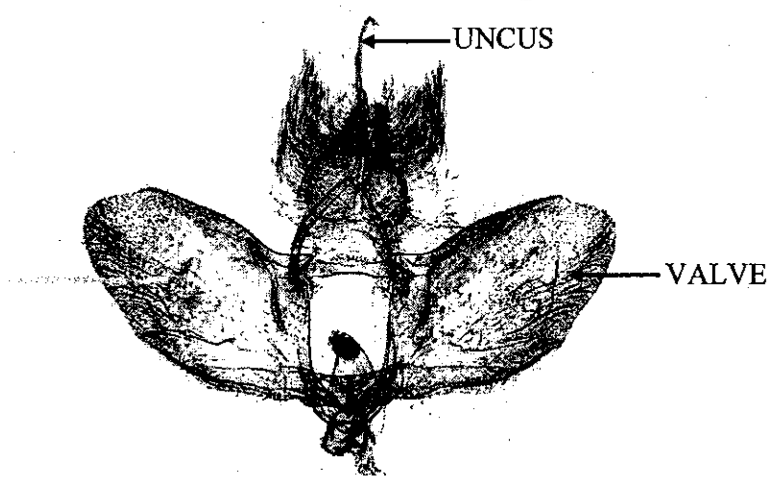


Figure C13. Ventral view male genitalia *Amorbia emigratella* Busck [Reproduced from Zimmerman (1978)].

Female genitalia: As in Fig. C14.

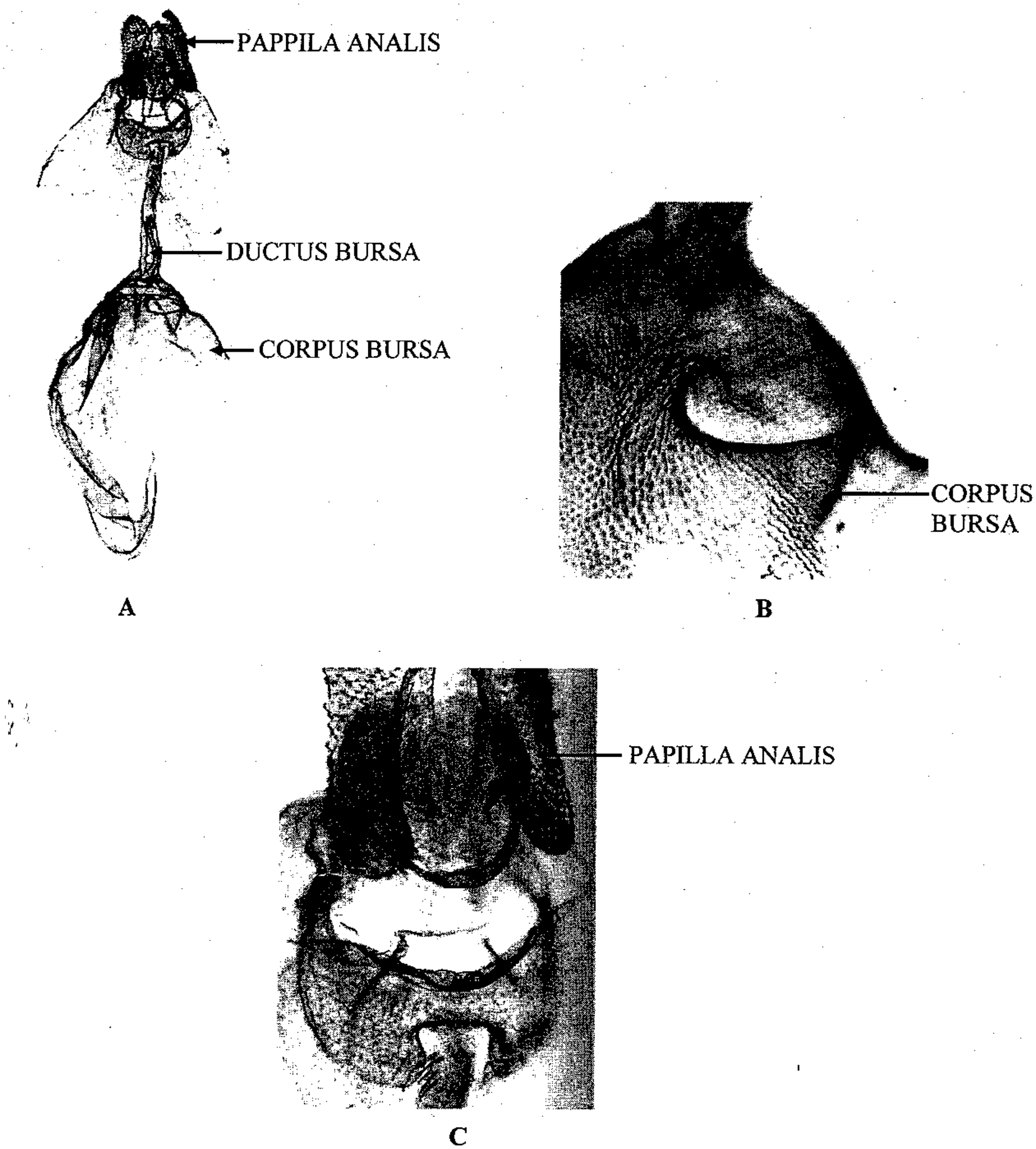


Figure C14. Female genitalia of *Amorbia emigratella* Busck A-entire genitalia, B-detail corpus bursa, C-detail papillae anales and associated structures [Reproduced from Zimmerman (1978)].

Pupa: As in Fig C15. Length 11.5 mm.

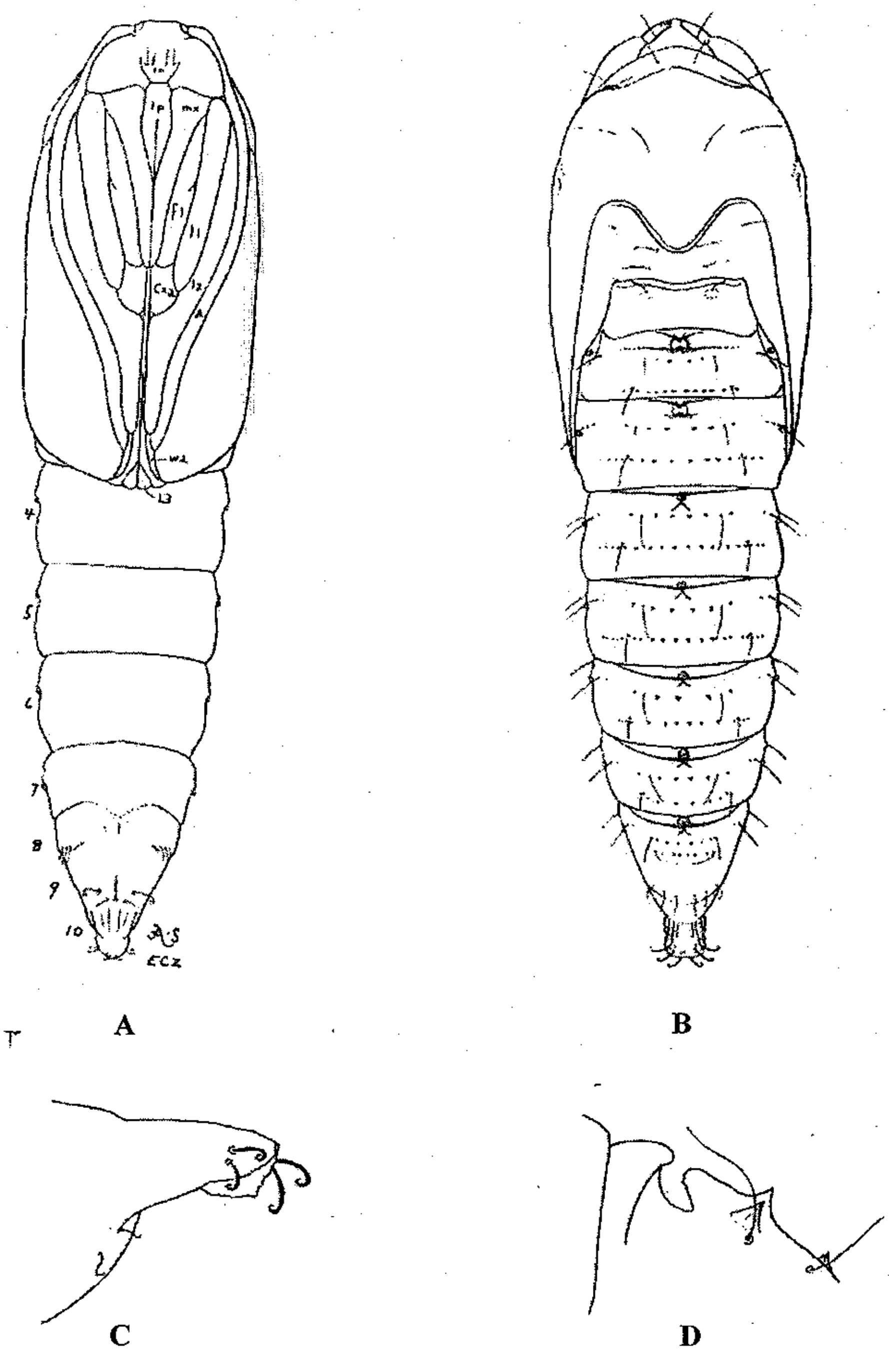


Figure C15. Pupa of *Amorbia emigratella* Busck A-ventral view pupa, B-dorsal view pupa, C-detail lateral view left side cauda of pupa, D-outline left side 8th abdominal tergite. A-antenna; Cx2-mesocoxa; f1-profemora; lb-labrum; lp-labial palpus, l1, l2, l3-legs; mx-galea of maxilla (probscis), W2-hindwing. Ventral setae mostly omitted. [Reproduced from Zimmerman (1978)].

Larva: As in Fig C16.

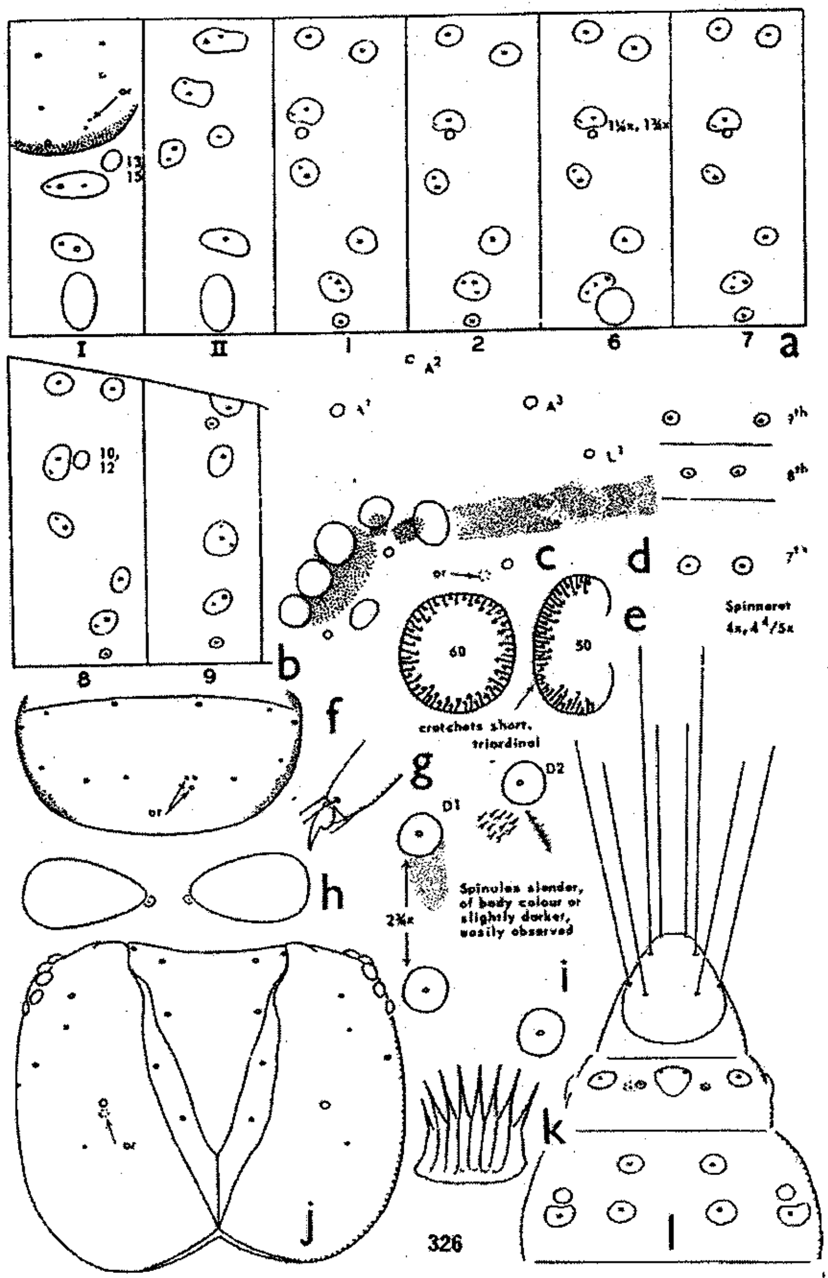


Figure C16. Larva of *Amorbia emigratella* Busck a, setal map of the pro- and mesothorax and abdominal segments, 1,2,6, and 7; b, the same of abdominal segments 8 and 9; c, ocellar area of the left side of the head; d, the V1 setae along the midline of the abdominal sternites 7, 8, and 9; e, crochets of a mid-abdominal and an anal proleg; f, prothoracic shield; g-lateral aspect of a thoracic leg tarsus; h, metacoxae and the associated V1 setae; I, dorsal setae and dermal spinules of an anterior abdominal tergum; j, frontal aspect of head; k anal fork; l dorsal aspect of abdomal segments 8. 9, and 10 [Quoted and Reproduced from Zimmerman (1978)].

Appendix D. Biology of *Epiphyas postvittana*

Population phenology

In much of Australia, *E. postvittana* completes three generations annually (Danthanarayana 1975, Geier and Briese 1980, Thomas 1989). More than three generations can be completed if temperatures and host plants are favorable (MacLellan 1973, Thomas 1989, Madge and Stirrat 1991, Bailey 1997). For example, four generations can be completed in southeastern Australia where it is warmer (Buchanan et al. 1991, Magarey et al. 1994). In contrast, two generations occur in Tasmania (Evans 1937), New Zealand (McLaren and Fraser 1992), and the UK (Bradley 1973). In Australia, generations do not overlap, but they do in the UK (Bradley 1973). Within a generation several life stages of the insect (e.g., eggs and larvae) may co-occur (Danthanarayana 1975).

Epiphyas postvittana is more abundant during the second generation than during other generations (MacLellan 1973, Madge and Stirrat 1991). Thus, the second generation causes the most economic damage (Evans 1937, Thomas 1975, Madge and Stirrat 1991, Lo and Murrell 2000) as larvae move from foliage to fruit (MacLellan 1973, Magarey et al. 1994). The size of the third generation is typically smaller than the previous two due to leaf fall (including attached larvae) as temperatures decline in autumn (Thomas 1975). The level of damage caused by *E. postvittana* is not related to the potential number of generations that the pest may complete (Geier and Briese 1981).

Epiphyas postvittana does not diapause (Geier and Briese 1981), rather, development is slowed under cold winter temperatures (MacLellan 1973, Geier and Briese 1981, Danthanarayana 1983, USDA 1984). In cold climates the pest overwinters as larvae (Nuttal 1983). Populations are only likely to increase at temperatures between 7.1° and 30.7°C (Danthanarayana et al. 1995). Comparison of dynamics of the pest in different geographic regions suggest the pest performs best under cool conditions (mean annual temperature of ~13.5°C) with moderate rainfall (~750 mm annually) and moderate-high relative humidity (~70%) (Danthanarayana et al. 1995). Hot, dry conditions may nearly eliminate a population (Danthanarayana 1983). Because *E. postvittana* causes damage in a wide range of climate types in Australia, pest status is not dictated by climate (Danthanarayana et al. 1995).

Stage specific biology

Cooler temperatures lead to longer development times for all stages of growth (Magarey et al. 1994). In summer it takes 4-6 weeks for the life cycle to be completed (Nuttal 1983).

Adults. Adult moths emerge after one to several weeks of pupation (Magarey et al. 1994). Female moths emerge from protective pupal nests (see below) and mate soon after emergence (Geier and Briese 1981) [although Danthanarayana (1975) suggests the preoviposition period is 2-7 days]. Females copulate for slightly less than 1 hr (Foster et al. 1995). Oviposition does not begin until females are 2- to 3-days old (Geier and Briese 1981). In a laboratory study, Foster et al. (1995) demonstrated that 3-day-old females were more likely to mate and acquire spermatophores than females that were 1-, 5-, or 7-days old. Two-day-old females produce a greater concentration of pheromone than 1-, 3-, 4- or 7-day-old females (Foster et al. 1995). The oviposition period lasts 1-21 days (Danthanarayana 1975). Females deposit eggs at night (USDA 1984).

Moths are quiescent during the day and may be found on foliage of hosts (Geier and Briese 1981). Flight occurs at dusk in calm conditions (Geier and Briese 1981, USDA 1984, Magarey et al. 1994). Adults are unlikely to disperse from areas with abundant, high-quality hosts (Geier and Briese 1981). Males will disperse farther than females. In a mark-release-recapture study, 80% of recaptured males and 99% of recaptured females occurred within 100 m of the release point (Suckling et al. 1994). Females do not appear to rely on plant volatiles to locate a host, but tactile cues are important (Foster and Howard 1998). Humidity influences the dispersal ability of the pest (Danthanarayana et al. 1995).

Adult longevity is influenced by host plant and temperature. In the laboratory, female longevity can vary between 10 days (Geier and Briese 1981) and 32.7 days (Danthanarayana 1975); males can live up to approximately 33 days (Danthanarayana 1975). In the field in Australia, the life span of adult *E. postvittana* is 2-3 weeks (Magarey et al. 1994). Heavier females live longer and lay more eggs than lighter females (Danthanarayana 1975). Female moths are typically larger than males (Danthanarayana 1975, Geier and Briese 1981).

Eggs. Females deposit eggs in egg masses. Within a mass, eggs are "stuck together like roof tiles" [see Fig 1] (Geier and Briese 1981) and are covered in a greenish "waxy secretion" (Evans 1937, Nuttal 1983). The number of eggs deposited in a mass is variable. Typically, females deposit 20 to 50 eggs per mass (Danthanarayana 1975, Geier and Briese 1981, Nuttal 1983, USDA 1984, Magarey et al. 1994). On apple leaves, eggs are laid in bunches of about 12 (Evans 1937). A female moth may produce up to 1492 eggs (Danthanarayana 1975, 1983), but the average number of eggs produced per female typically varies between 118-462 (MacLellan 1973, Danthanarayana 1975, Geier and Briese 1981, USDA 1984, Danthanarayana et al. 1995). Temperature and host plant heavily influence the number of eggs that will be produced. Fecundity is greatest at temperatures between 20 and 25°C, inclusive (Danthanarayana et al. 1995). Females prefer smooth leaf surfaces on which to deposit their eggs (Danthanarayana 1975, Geier and Briese 1981, Foster and Howard 1998).

Temperature is the main factor that affects the egg stage (Danthanarayana 1975). The egg stage lasts an average of 5-7 days at a temperature of 28°C (Danthanarayana 1975). Egg-hatching ceases at temperatures greater than 31.3°C (Danthanarayana 1975).

Larvae. *Epiphyas postvittana* typically completes five to seven instars (Danthanarayana 1975, Geier and Briese 1981, Magarey et al. 1994). Larvae emerge from eggs after 1-2 weeks and disperse, usually to the underside of the leaf, where they spin a "silken shelter" (i.e., a silken tunnel) and commence feeding (Danthanarayana 1975, Geier and Briese 1981, Nuttal 1983, USDA 1984, Thomas 1989). Although they are sheltered in silk, first instar larvae are more exposed to weather and insecticide treatments than are second and third instar larvae (Madge and Stirrat 1991, Lo et al. 2000). After approximately 3 weeks, larvae leave the silken tunnels for a new leaf (USDA 1984). Second and later instars have the ability to create their own protective feeding shelter by rolling a leaf or webbing multiple leaves together (Danthanarayana 1975, Lo et al. 2000), behaviors that are characteristic of the Tortricidae.

In spring, the pest feeds on new buds while later generations feed on ripened fruits (Buchanan et al. 1991). Feeding injury to fruit is typically caused by later instars (Lo et al. 2000). Fruit are not a preferred feeding site, so feeding on fruit is thought to happen by chance (Geier and Briese 1980, Lo et al. 2000). However, volatiles emitted by ripening fruit may be attractive to larvae (Suckling and Ioriatti 1996). On a fruit, the calyx offers protection from parasitoids and is probably the best feeding location for young larvae (Lo et al. 2000). Damage to the host plant is compounded by the pest, as it acts as a "vector" to spread fungal disease; feeding injury also predisposes the host to fungal infection (Buchanan et al. 1991, Bailey et al. 1995, Bailey 1997, Lo and Murrell 2000).

Larvae move vigorously when disturbed but are always connected to the leaf by a silken thread in case of being removed from a leaf (Nuttal 1983, USDA 1984). When larvae happen to fall to the ground, they feed on ground-cover hosts or can survive without feeding for several months (Evans 1937, Thomas 1975, USDA 1984). Control can be initiated by keeping the ground clear of preferred hosts by mowing or removing weeds (Evans 1937, Thomas 1975).

Larvae prepare to overwinter by locating "sheltering niches," which may be mummified fruit or ground vegetation (Thomas 1975). Overwintering larvae can utilize alternate hosts, including several weed species, for food and to form shelters (Buchanan et al. 1991). Larvae may also survive winters without feeding for up to 2 months (USDA 1984).

Pupae. Pupation is completed within the "nests" made from rolled-up leaves (Danthanarayana 1975, Geier and Briese 1981, Nuttal 1983, Magarey et al. 1994). The pupal stage lasts 2-3 weeks (Evans 1937).

Several studies describe the developmental thresholds and accumulated degree days necessary for the completion of each phenological stage (Table D1). A phenological model developed with parameters from Danthanarayana (1975) and Geier and Springett (1976) performed better when the accumulation of degree-days began at "budburst" rather than at a start date of July 1 (Madge and Stirrat 1991). Although important discrepancies between the predicted and observed population dynamics were noted, the performance of the model was considered acceptable (Madge and Stirrat 1991).

Table D1. Developmental threshold and degree day requirements for *E. postvittana*.

Stage	Developmental threshold (°C)	Degree Days ± SE	Notes	Reference
Egg	7.0	131 ± 1	Lab study	(Geier and Briese 1981)
	7.5	133.7	Lab study	(Danthanarayana 1975)
Larva	6.9	380.8 ± 13.2	Average over several host plants; from authors' Table 2	(Danthanarayana et al. 1995)
	7.5 lower, 31-32 upper	345.9	Lab study	(Danthanarayana 1975)
Pupa	3.8	175.0 ± 11.1	Average over several host plants; from authors' Table 2	(Danthanarayana et al. 1995)
	7	132 ± 2	Lab study	(Geier and Briese 1981)
	7.5 lower, 31-32 upper	129.1	Lab study	(Danthanarayana 1975)
Adult	-3.2	393.1 ± 9.4	Adult longevity; from authors' Table 3	(Danthanarayana et al. 1995)
	6.9	NA	Female; lab study	(Geier and Briese 1981)
	7.1	NA	Male; lab study	(Geier and Briese 1981)
	7.5	29.9	Preoviposition period	(Danthanarayana 1975)
	7.5	83	Eclosion to 50% oviposition	(Danthanarayana 1975)
Neonate to pupa	7	265-551	Range influenced by host quality	(Geier and Briese 1981)
Complete life cycle	7.5	620.5	Egg to first egg	(Danthanarayana 1975)
	7.5	673.6	Egg to 50% oviposition	(Danthanarayana 1975)

Photoperiod
Epiphyas postvittana does not diapause, so populations are less influenced by photoperiod.

Water
Moist conditions favor this species (Nair et al. 1988, Bailey 1997, Lo and Murrell 2000). Rainy conditions increase the density of host plants and indirectly favor the pest population (Buchanan et al. 1991, Magarey et al. 1994).

Biotic Factors
Epiphyas postvittana is vulnerable to several natural predators and parasites (Buchanan et al. 1991, Magarey et al. 1994, Il'ichev and Flett 1999).

INSECTS NOT KNOWN TO OCCUR IN THE UNITED STATES

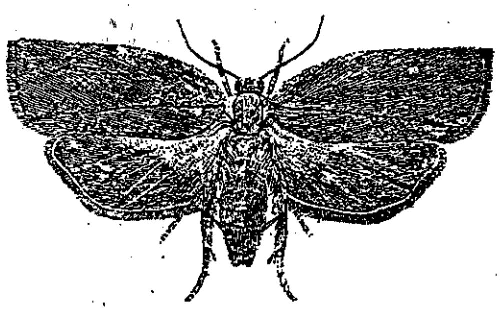
LIGHT-BROWN APPLE MOTH (Austrotortrix postvittana (Wlk.))

Economic Importance: Light-brown apple moth has become a major pest of apples in Tasmania (Australia) and certain parts of New Zealand. In years of abundant populations the tortricid may cause as much as 25 percent loss of the apple crop in Tasmania. It is listed as one of the most troublesome pests of citrus in New Zealand. Damage to fruit in storage has also been recorded.

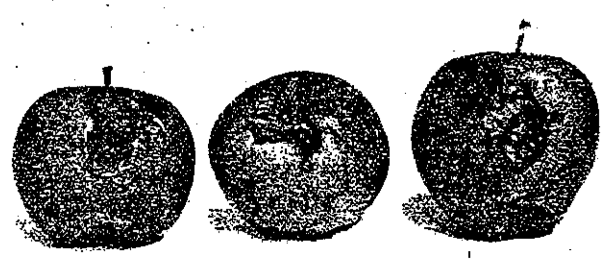
Distribution: This pest is indigenous to Australia and occurs in all apple-growing areas of that country but is chiefly found in a belt around the coast extending inland about 200 miles at the widest point. It also occurs in New Zealand, New Caledonia, Hawaii and England.

Hosts: Apple, litchee, strawberry, grape, pear, orange, apricot, currant, oak, pine, chrysanthemum, rose, eucalyptus and acacia. Also other garden and greenhouse plants.

Description and Life History: Life history of A. postvittana in Tasmania is as follows: Moths begin appearing in orchards during early summer. They are pale brown in color, less than half-an-inch long when resting. If disturbed, they make short erratic flights. Eggs are laid on apple leaves in batches of about twelve. They are pale green and almost flat. Young larvae feed principally on the underside of leaves in silken tunnels lying alongside the veins or the midrib. After about three weeks they abandon tunnels and continue to feed causing "ragging" and curling of foliage and pitting and scarring of fruit. The larvae pupate in folded or webbed leaves. In late summer another brood of moths emerge. Small caterpillars from this brood feed as long as the leaves remain on trees. Then the larvae drop and feed on cover crops or survive on orchard floor without feeding. At end of September when early shoots appear these larvae climb the trees and feed on such growth as is available. By the "pink-bud" stage a large proportion of blossom clusters nearest ground may be infested. This brood completes development in late October and gives rise to flights of moths. In Tasmania, there may be 3 generations a year on evergreens. (Prepared by Plant Pest Survey Section in cooperation with other ARS agencies). CEIR 7(9) 3-8-57.



Adult greatly enlarged

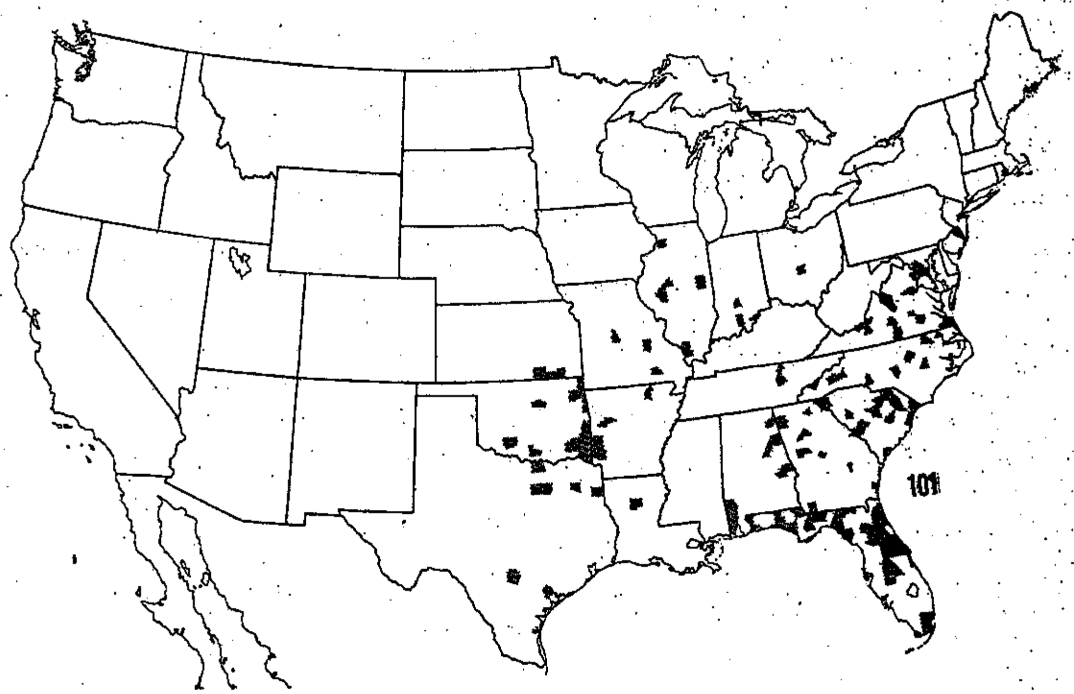


Characteristic larval damage to fruit

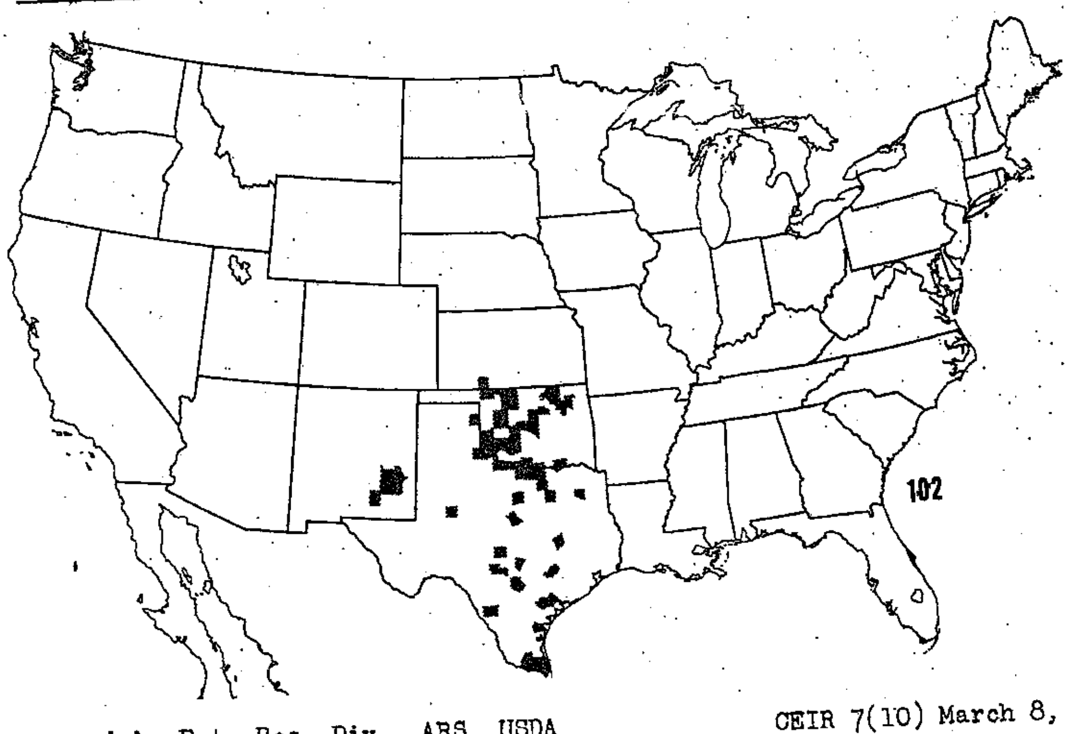
Figures. Adult from Australian Insects, K. C. McKeown, 1944, 303 pp. Sydney. Damage from Suppl. Tasmania Jour. Agric. 8(3):1-18, 1937, J. W. Evans.

DISTRIBUTION OF RANGE GRASSHOPPERS

Paradalophora phoenicoptera (Burmeister)



Paradalophora saussurei (Scudder)



U.S. Department of Agriculture

APHIS-PPQ

APHIS 81-45
September 1984

PESTS NOT KNOWN TO OCCUR IN THE UNITED STATES OR OF LIMITED DISTRIBUTION, NO. 50: LIGHT-BROWN APPLE MOTH

Prepared by K. Whittle, Biological Assessment Support Staff, PPQ, APHIS, USDA, Federal Building Room 634, Hyattsville, MD 20782

Pest

LIGHT-BROWN APPLE MOTH
Epiphyas postvittana (Walker)

Selected Synonyms

Austrotortrix postvittana (Walker)
Tortrix postvittana Walker

Order: Family

Lepidoptera: Tortricidae

Economic Importance

The larva of *Epiphyas postvittana* is a serious pest of fruit and ornamentals in Australia and New Zealand. As a pest of pome fruits, particularly apples, it probably ranks second to *Cydia pomonella* (L.), codling moth. During a severe outbreak, damage by *E. postvittana* to fruit may be as much as 75 percent. In Tasmania, this species is the most injurious pest of apples. In years of abundance, populations of the light-brown apple moth may cause as much as 25 percent loss of the apple crop. This pest damages fruit in storage; a few larvae may ruin a whole case. The markings on the fruit render it unfit for export (Danthanarayana 1975, Evans 1937).

Hosts

Larvae of light brown apple moth feed on a wide range of plants. Hosts include *Acacia* spp. (wattles), *Actinidia chinensis* (kiwi), *Adiantum* sp., *Amaranthus hybridus* (smooth pigweed), *Amaranthus patulus* (foxtail), *Aquilegia* sp., *Arbutus* sp., *Arctotheca calendula* (capeweed), *Artemisia* sp., *Astartea* sp., *Aster subulatus* (bushy starwort), *Baccharis* sp. (groundsel-bush), *Boronia ledifolia* (boronia), *Brassica oleracea* (wild cabbage), *Breynia* sp., *Buddleia* sp., *Bursaria* sp., *Calendula officinalis* (pot-marigold), *Callistemon* sp., *Camellia* sp., *Campsis* sp., *Cassia* sp., *Ceanothus* sp., *Centranthus* sp., *Centranthus ruber* (red valerian), *Chamaecyparis lawsoniana* (Port-Orford-cedar), *Chenopodium album* (lambsquarters), *Choisya* sp., *Chrysanthemum* sp. (chrysanthemum), *Citrus* sp., *Clematis* sp., *Clerodendrun* sp., *Correa speciosa*, *Cotoneaster* sp., *Crataegus* sp., *Cucurbita pepo* (pumpkins), *Cydonia* sp., *Dahlia* sp., *Datura* sp., *Daucus* sp., *Dodonaea* sp., *Eriobotrya* sp., *Eriostemon* sp., *Escallonia* sp. (escallonia), *Eucalyptus* sp., *Euonymus* sp., *Euonymus japonica*, *Euphorbia* sp., *Feijoa* sp., *Forsythia* sp., *Fragaria* sp. (strawberry), *Fortunella* sp., *Gelsemium* sp., *Genista* sp., *Gerbera* sp., *Grevillea robusta* (silk-oak), *Hardenbergia* sp., *Hebe* sp., *Hedera* sp. (ivy), *Helichrysum* sp., *Humulus lupulus* (hops), *Hypericum* sp. (St. John's wort), *Jasminum* sp. (jasmine), *Juglans regia* (English walnut), *Lathyrus* sp., *Lavandula* sp. (lavender), *Leptospermum* sp., *Leucodendron* sp., *Ligustrum* sp.

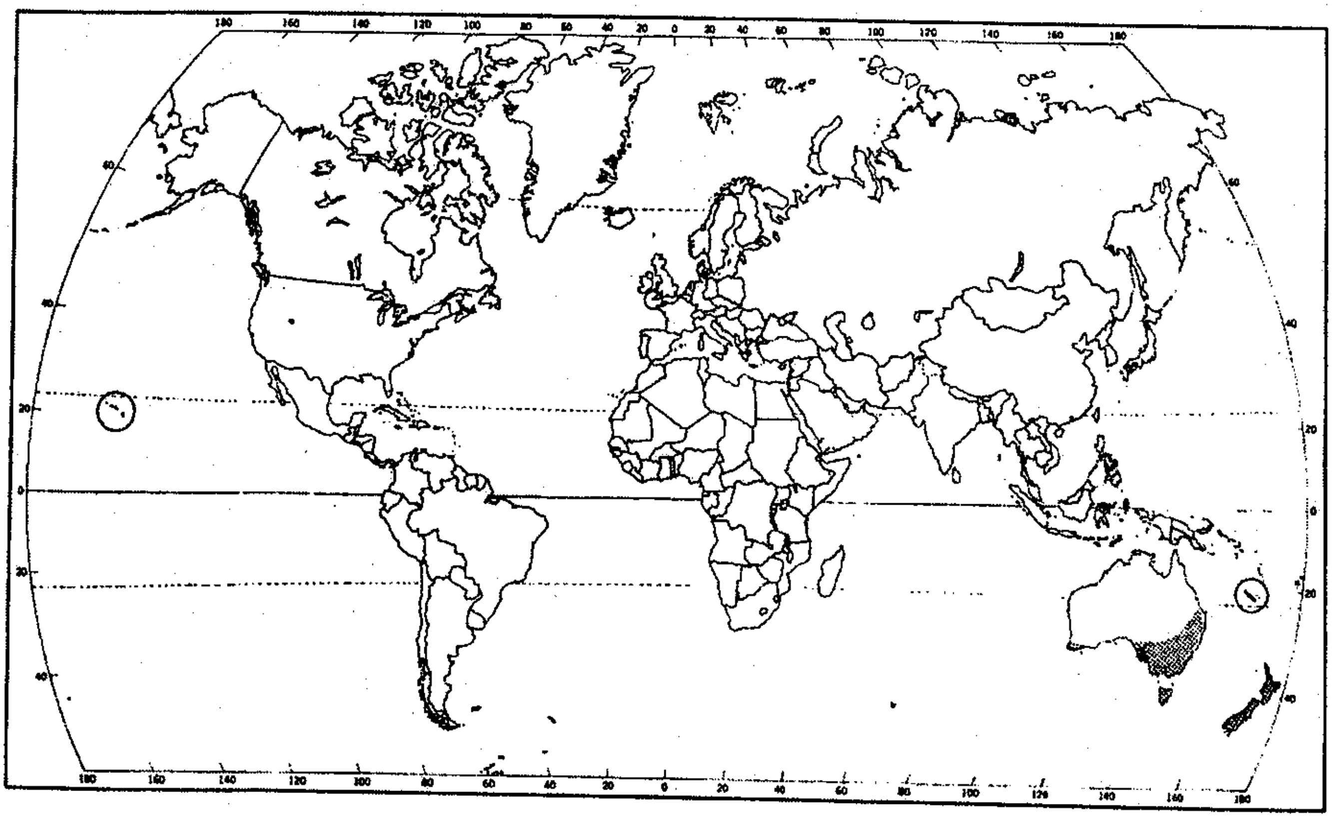
(privet), Ligustrum ovalifolium (California privet), Linum sp., Litchi sp., Lonicera sp., Lupinus sp. (lupine), Lycopersicon esculentum (tomato), Macadamia sp., Malus sylvestris (apple), Mangifera sp., Medicago polymorpha, Medicago sativa (alfalfa), Melaleuca sp., Mentha sp. (mint), Mesembryanthemum sp. (fig-marigold), Michelia sp., Monotoca sp., Myoporum sp., Oxalis sp., Parthenocissus sp., Pelargonium sp., Persoonia lanceolata (bonewood), Petroselinum sp., Philadelphus sp., Photinia sp., Phyllanthus sp., Pinus sp. (pine), Pinus patula (Mexican yellow pine), Pinus radiata (Monterey pine), Pipturus sp., Pittosporum sp., Plantago lanceolata (buckbean), Platysace sp., Polygala sp., Polygonum sp. (knotweed), Prunus armeniaca (apricot), Prunus avium (sweet cherry), Prunus domestica (plum), Prunus persica (nectarine, peach), Pteris sp., Pulcaria sp. (fleabane), Pulcaria dysenterica (fleabane), Pyracantha sp., Pyrus communis (pear), Quercus sp. (oak), Ranunculus sp., Raphanus raphanistrum (wild radish), Reseda odorata (mignonette), Ribes spp. (currants), Ribes uva-crispa (European gooseberry), Rosa sp. (rose), Rubus fruticosus (European blackberry), Rubus hawaiiensis, Rumex acetosella (sorrel), Rumex crispus (curly dock), Salvia sp., Santalum sp., Senecio sp. (groundsel), Sida sp., Sisymbrium officinale (hedge mustard), Smilax sp., Solanum tuberosum (potato), Sollya sp., Tithonia sp., Trema sp., Trifolium glomeratum (cluster clover), Trifolium repens (white clover), Trifolium subterraneum (subterranean clover), Triglochin sp., Ulex europaeus (gorse), Urtica dioica (nettle), Vaccinium sp., Viburnum sp., Vicia faba (broadbean), Vicia hirsuta (tiny vetch), Vicia sativa (vetch), Vinca sp., Vitis sp. (grape), Wikstroemia foetida, Wilkesia sp., and Wisteria sp. (Danthanarayana 1975 and 1983, Ferro 1976, Geier and Briese 1981, Zimmerman 1978).

General Distribution

This species is indigenous to Australia (Queensland, New South Wales, Victoria, South Australia, and Tasmania) and has been introduced into Hawaii, New Caledonia, New Zealand, and southwestern England (Commonwealth Institute of Entomology 1957, Geier and Briese 1981). It has also been introduced into southwestern Western Australia (D. Briese, personal communication 1984).

Characters

ADULTS (Fig. 1) - Male smaller than female, length 5-10 mm, wingspan 12-24 mm. Wing venation in Fig. 2. Distinguished by forewing abruptly divided medially into pale basal and darker apical areas; female length 5-12 mm and wingspan 12-27 mm, forewings less marked than male's (Danthanarayana 1975, Zimmerman 1978).

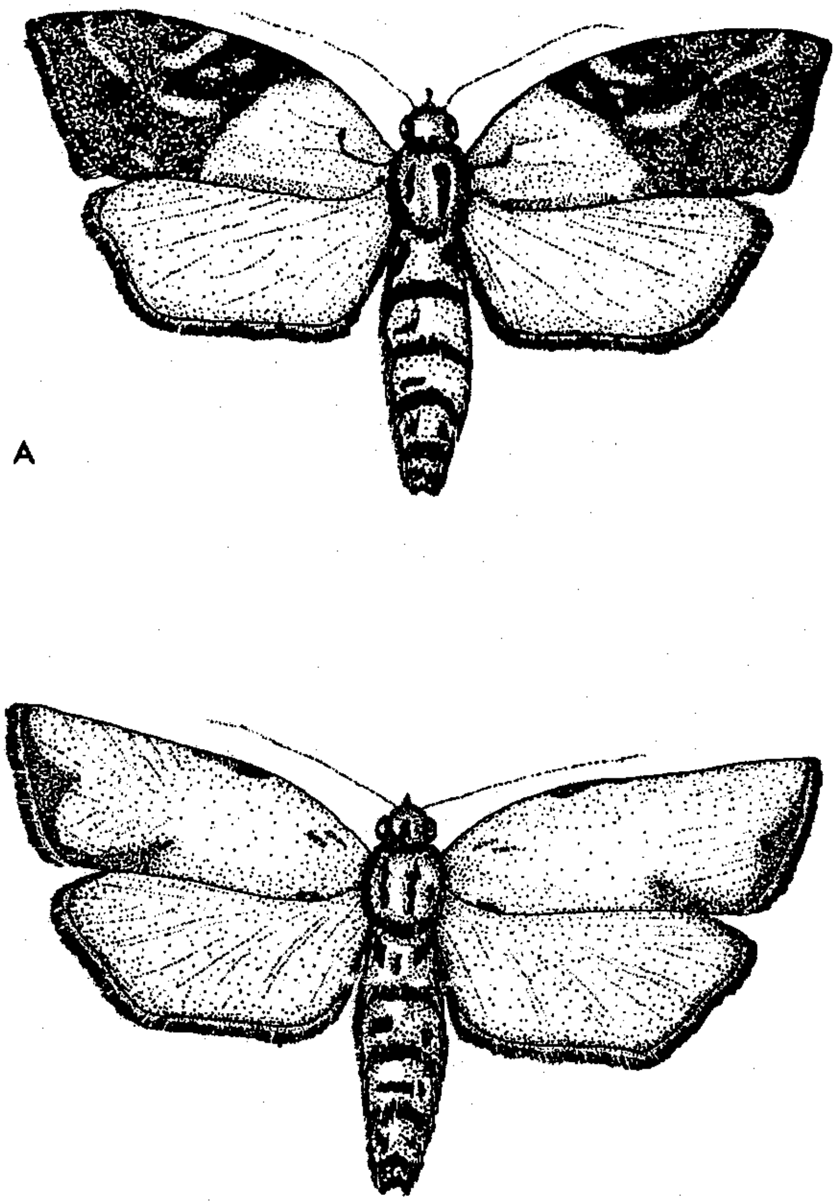


Epiphyas postvittana distribution map prepared by Non-Regional Administrative Operations Office and Biological Assessment Support Staff, PPQ, APHIS, USDA

Male. Antenna weakly dentate ciliate, length of cilia about equal to width of flagellum. Forewing: basal half light buff or pale yellow; distal half dark brown, ferruginous; oblique narrow median fascia darker, inner edge sharply defined, straight, sometimes slightly sinuate at middle; pre-apical spot obscure, its inner margin usually defined by ferruginous ground color separating it from median fascia; well-developed costal fold from base to about two-fifths (Bradley, Tremewan, and Smith 1973), distinct V-shaped boundary when folded (Fig. 3) (Danthanarayana 1975). Hindwing gray (Bradley, Tremewan, and Smith 1973).

Male extremely variable with numerous recurring forms. In strongly marked forms, distal half of forewing reddish brown to blackish with purplish mottling; pale basal half may be sparsely black speckled. Lightly marked forms resemble female; extreme form with outer half of forewing light and pre-apical spot distinct (Bradley, Tremewan, and Smith 1973).

(Fig. 1)

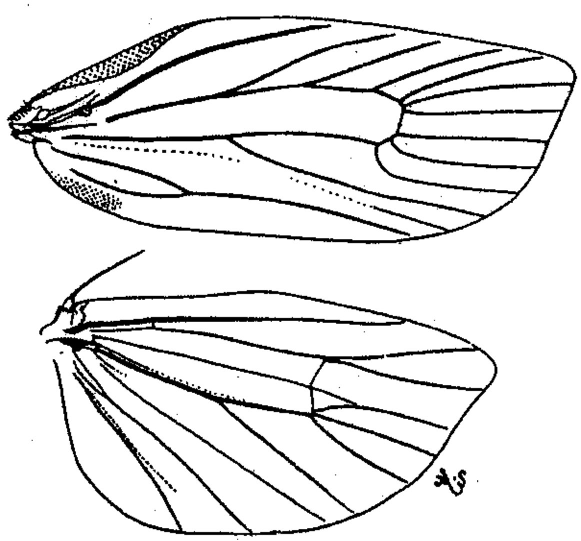


A

B

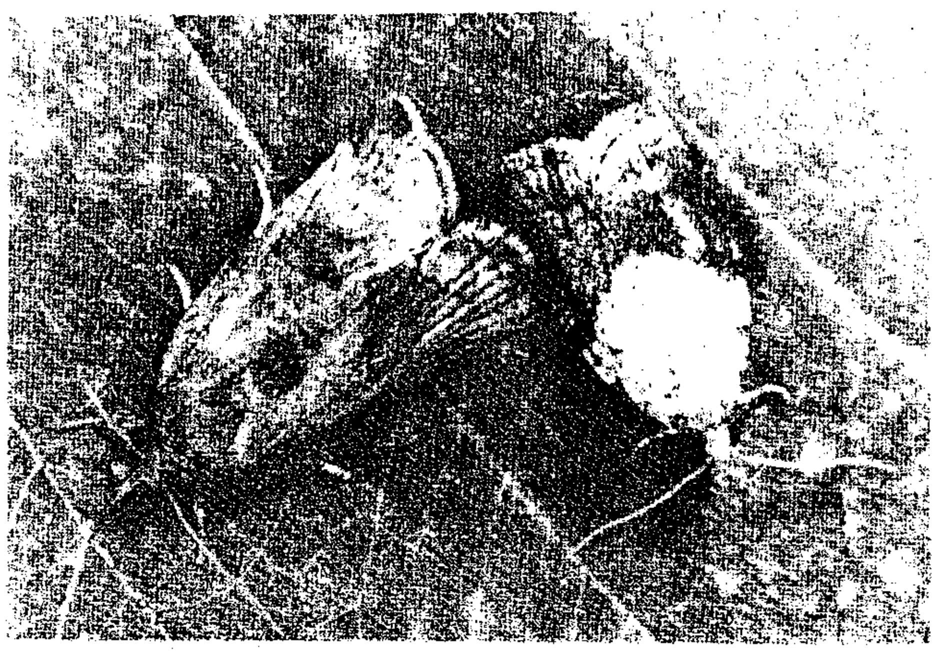
Epiphyas postvittana adults, dorsal view: A. Male. B. female (From Ferro 1976).

(Fig. 2)



Wing venation of Epiphyas postvittana male, dorsal view (From Zimmerman 1978).

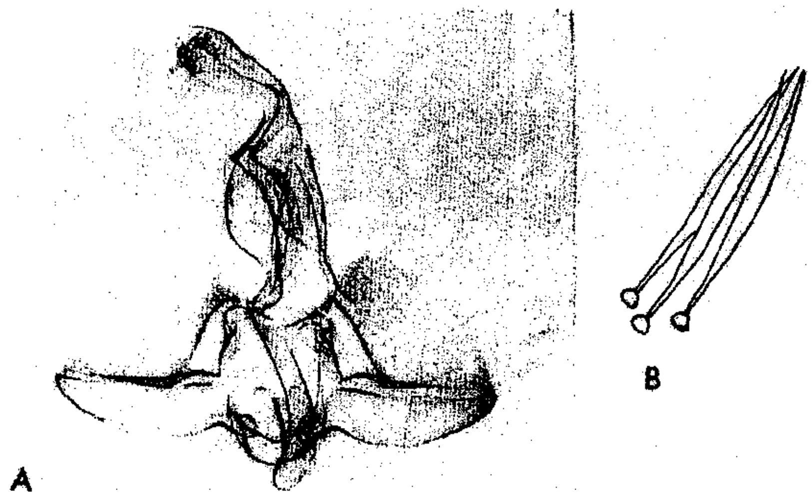
(Fig. 3)



Epiphyas postvittana adults, dorsal view: Female (left); male (right) (From Geier and Briese 1981).

Male genitalia (Fig. 4A). Internal sac of aedeagus bears two to four long, narrow, flattened cornuti (Fig. 4B). These are deciduous and may be missing from mated specimens, but points of articulation can still be seen (Zimmerman 1978).

(Fig. 4)



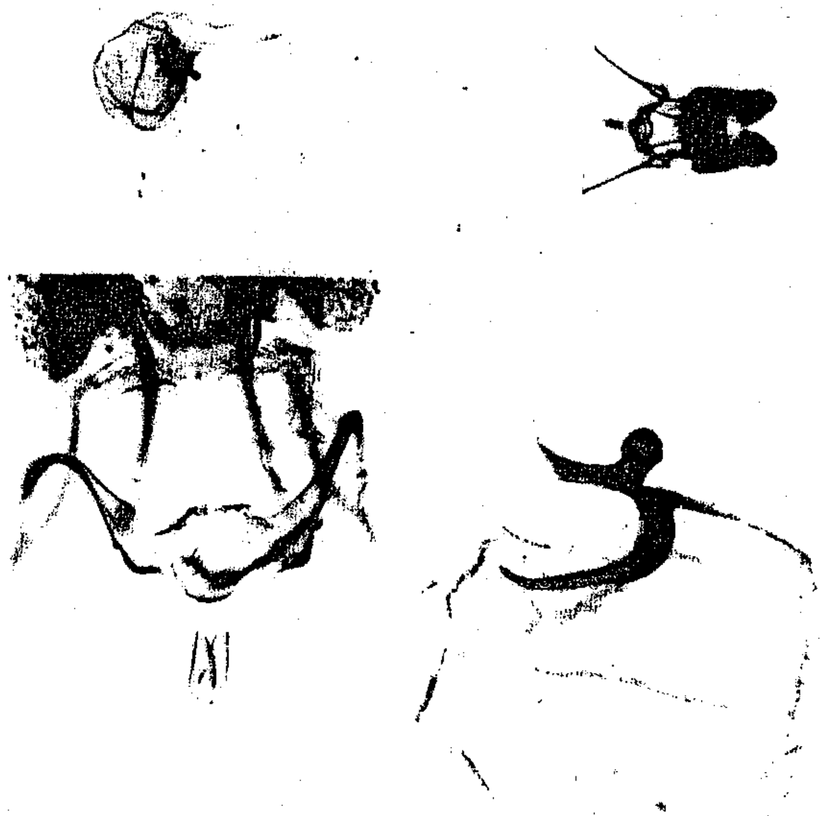
Epiphyas postvittana: A. Male genitalia, dorsal view. B. Three long, rodlike cornuti, dorsal view (From Zimmerman 1978).

Female. Antenna minutely ciliate. Forewing longer than male's, apex produced, contrast between basal and distal halves less than in male, median fascia usually reduced. Variation minor, forewing irrorate with black (Bradley, Tremewan, and Smith 1973). Female genitalia (Fig. 5).

Epiphyas postvittana may be confused with Amorbia emigratella Busck (Mexican leafroller), but E. postvittana has ocelli which are lacking in A. emigratella, the undersides of the hindwings are conspicuously immaculate as in A. emigratella and the second abdominal tergite lacks the conspicuous median pit near the base which is present in A. emigratella (Zimmerman 1978).

EGGS - Pale green to pale brown, almost flat (U.S. Department of Agriculture 1957), 0.84 by 0.95 mm (Danthanarayana 1975).

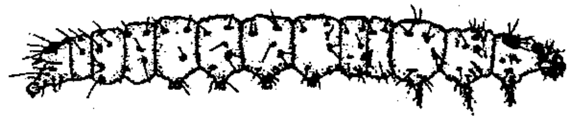
(Fig. 5)



Epiphyas postvittana: Female genitalia, holotype (British Museum slide 1815) (From Zimmerman 1978).

LARVAE (Fig. 6) - First instar pale yellow, head dark brown. Later instar head and prothoracic plate pale brown. Length of full-grown larvae 10-18 mm, body medium green, darker central stripe, two side stripes (Ferro 1976).

(Fig. 6)

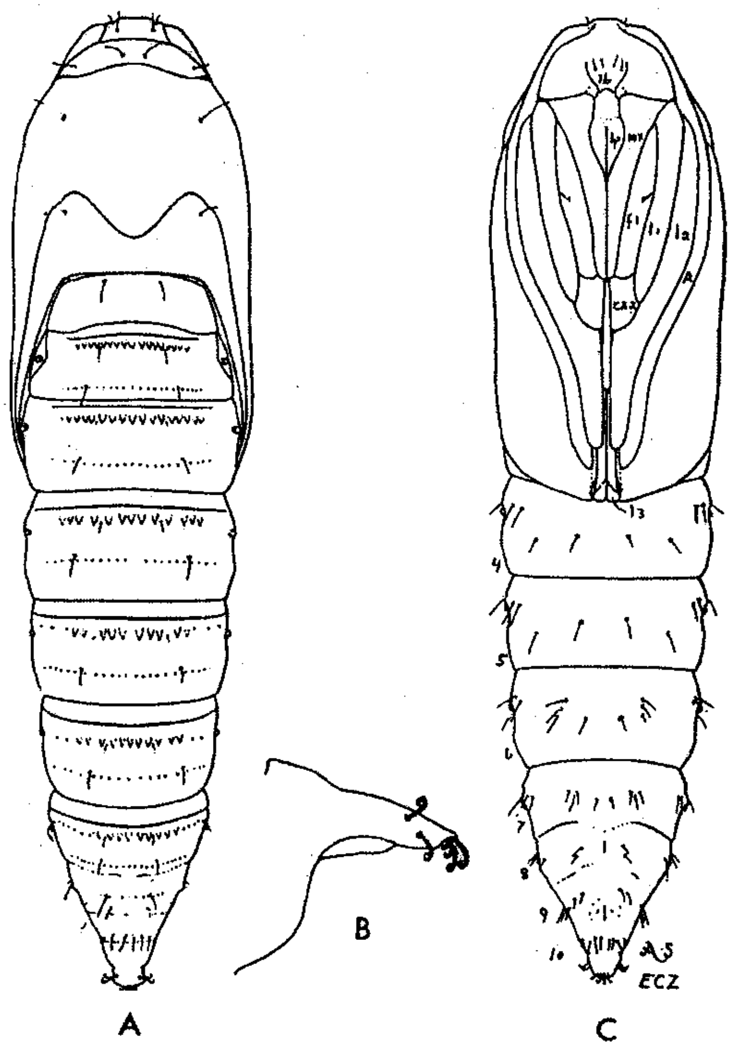


Epiphyas postvittana larva, lateral view (From Ferro 1976).

E. postvittana larvae are green, as in Amorbia emigratella, but prothorax does not have a black line on each lateral margin as does the larva of A. emigratella (Zimmerman 1978).

PUPAE (Fig. 7) - Newly formed, green; later, medium brown. Male averages 2.5 by 7.6 mm; female 2.9 by 9.8 mm (Danthanarayana 1975).

(Fig. 7)



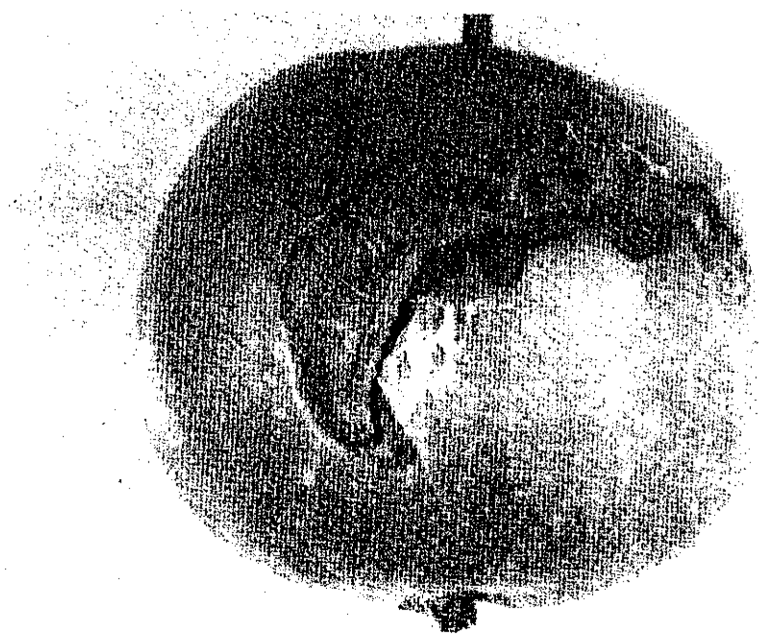
Epiphyas postvittana pupa. A. Dorsal view. B. Cauda, left lateral view. C. Ventral view.

cx2 - Mesocoxa; f1 - profemora; lb - labrum; lp - labial palpus; l1, l2, l3 - legs; mx - galea of maxilla (proboscis) (From Zimmerman 1978).

Characteristic Damage

Larval feeding on fruit (Fig. 8) results in large irregular blemishes. These blemishes may callous over and the fruit remain on the tree, or wet conditions may allow the entry of rot organisms. Larvae may excavate small round pits and produce scars similar to the "stings" of the larvae of *Cydia pomonella*. Clusters of fruit are particularly susceptible. Larvae entering the fruit through the calyx may cause internal damage. Feeding on the foliage causes ragging and curling (Evans 1937, Ferro 1976, U.S. Department of Agriculture 1957).

(Fig. 8)



Epiphyas postvittana larva, dorsolateral view, showing damage to an apple (Geier and Briese 1981).

Detection Notes

The movement of this pest from country to country may occur in one of several ways. Three possible pathways are as immatures with fresh fruit, immatures with propagative material, and as adults on aircraft. Although some of its hosts are prohibited because of other pests, many of its hosts are enterable into the United States subject to inspection under various regulations, mainly Title 7, Part 318.13, Part 319.37, and Part 319.56 of the Code of Federal Regulations.

The total number of E. postvittana interceptions at U.S. ports of entry was 63 in the past 13 years. Only larval and pupal stages have been intercepted. Interceptions were common on Malus sylvestris (apple) in cargo from Australia (13 times including 7 from Tasmania) and New Zealand (5). Cargo interceptions were made from Australia in Fragaria sp. (strawberry) and Pyrus communis (pear); and New Zealand in Capsicum spp. (peppers), Fragaria sp. (strawberry), Prunus spp. (cherries), P. armeniaca (apricot), P. domestica (plum), P. persica (peach), and Ribes nigrum (black currant). This pest has also been intercepted a few times in baggage and stores.

This species may be detected in the following ways.

1. Search for overlapping egg masses on leaves. The egg mass may be jet black if parasitized by Trichogramma sp. (a trichogrammatid wasp).

2. Inspect fruit for irregular brown areas, round pits, or scars. Look for evidence of feeding at the calyx end of the fruit. If no external signs of the larva are present, probe the calyx areas. If frass is discovered, cut out the calyx area below it and break the apple open. The larva will be found at the calyx end or in the endocarp.

3. Inspect for ragged and curled leaves. Open rolled up leaves to search for larvae.

4. Watch for adults resting on the underside of the leaves during the day.

Biology

In Tasmania, adults begin appearing in orchards during early summer. They lay their eggs on apple leaves. The newly hatched larvae feed principally on the underside of leaves in silken tunnels. After about 3 weeks, they abandon their tunnels and continue feeding. They pupate in folded or webbed leaves. In late summer, another generation of moths emerges. Larvae from this generation feed as long as leaves remain on trees. When the leaves fall, the larvae drop and feed on cover crops, but they can survive on the orchard floor without feeding as long as 2 months. The next spring, they return to the trees to feed on the green shoots and later in the blossom clusters (Evans 1937, U.S. Department of Agriculture 1957).

In Australia, adults rest under leaves during the day. If disturbed, they make short erratic flights. They become active at dusk and oviposit either late in the evening or during the night. Females of the first summer generation mate shortly after emergence and lay their eggs 2 or 3 days later. They usually lay 20-25 eggs each, in partly overlapping masses on smooth surfaces, mostly on the leaves of host plants. They normally produce 100-200 eggs in a lifetime of about 10 days. Fecundity depends on the season, and under field conditions, females may lay 209-455 eggs.

After 1-2 weeks, the larvae hatch. They disperse actively, either by crawling or by dropping on silken threads, before constructing a silken shelter, often on the underside of a leaf near the midrib or a vein. After the first moult, they construct typical leaf rolls (nests) by webbing one or more leaves together, or by webbing a leaf onto the surface of a fruit. During the fruiting season, they also make nests among clusters of fruits, and sometimes tunnel into the fruits through the calyx. If disturbed, young larvae tend to withdraw to the end of their tunnels, while older larvae will wriggle violently, and either drop to the ground or hang suspended by a silken thread. The larva passes through six instars, but its appearance remains generally similar throughout, except for increase in size. Very rarely under laboratory conditions, five or seven instars develop but never four. Pupation occurs within the nests (Danthanarayana 1975 and 1983, Evans 1937, Ferro 1976, Geier and Briese 1981, U.S. Department of Agriculture 1957).

The longest mean life span in experiments was 33 days for females and 26 days for males at about 12° C. The shortest mean life span measured was 3 days at 31° C. The pest has no winter resting stage, being active throughout the year. Adult activity is, however, much slower during the winter. There are three generations a year in Australia. The favorable temperature range is between 15 and 25° C. A long, hot summer does not support *Epiphyas* populations; the pest prefers regions with cool climates (Danthanarayana 1975).

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