

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.

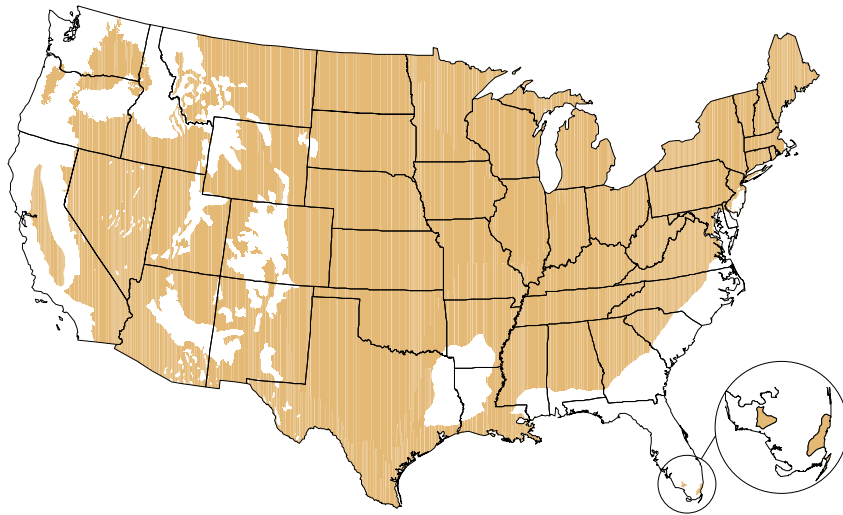


Figure 2. Predicted distribution of *Epiphyas postvittana* in the continental US. Southern Florida is enlarged for detail.

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 (*Crococsmia* 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 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 (Nuttall 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.

References:

- Armstrong, K. F., C. M. Cameron, E. R. Frampton, and D. M. Suckling. 1997.** Aliens at the border and cadavers in the field: A molecular technique for species identification, pp. 316-321, Proceedings of the 50th New Zealand Plant Protection Conference. New Zealand Plant Protection Society, Rotorua, New Zealand. [PDF](#)
- Bailey, P., G. Baker, and G. Caon. 1996.** Field efficacy and persistence of *Bacillus thuringiensis* var. *kurstaki* against *Epiphyas postvittana* (Walker) (Lepidoptera:

- Tortricidae) in relation to larval behaviour on grapevine leaves. Australian Journal of Entomology 35: 297-302. [PDF](#)
- Bailey, P., A. Catsipordas, G. Baker, and B. Lynn. 1995.** Traps in monitoring lightbrown apple moth. The Australian Grapegrower & Winemaker: 130-132. [PDF](#)
- Bailey, P. T. 1997.** Lightbrown apple moth control options for the 1997-8 season. Australian & New Zealand Wine Industry Journal 12: 267-270. [PDF](#)
- Bellas, T., R. Bartell, and A. Hill. 1983.** Identification of two components of the sex pheromone of the moth, *Epiphyas postvittana* (Lepidoptera, Tortricidae). Journal of Chemical Ecology 9: 503-512. [PDF](#)
- Bradley, J. D. 1973.** *Epiphyas postvittana* (Walker), pp. 126-127, British Tortricoid moths; Cochylidae and Tortricidae; Tortricinae. The Ray Society, London. [PDF](#)
- Bradley, J. D., W. G. Tremewan, and A. Smith. 1979.** List of British species of Tortricidae: Olethreutinae, London.
- Bradley, S., J. Walker, C. Wearing, P. Shaw, and A. Hodson. 1998.** The use of pheromone traps for leafroller action thresholds in pipfruit., pp. 173-178, Proceedings of the 51st New Zealand Plant Protection Conference. New Zealand Plant Protection Society, Rotorua, New Zealand. [PDF](#)
- Brockerhoff, E., H. Jactel, A. Leckie, and D. Suckling. 2002.** Species composition and abundance of leafrollers in a Canterbury pine plantation. New Zealand Plant Protection 55: 85-89. [PDF](#)
- Brown, D. J., and A. L. Il'ichev. 2000.** The potential for the removal of organo-phosphate insecticides from stone-fruit production in the Goulburn Valley, Australia. Acta Horticulturae 525: 85-91. [PDF](#)
- Buchanan, G. 1977.** The seasonal abundance and control of light brown apple moth, *Epiphyas postvittana* (Walker) (Lepidoptera: Tortricidae), on grapevines in Victoria. Australian Journal of Agricultural Research 28: 125-132. [PDF](#)
- Buchanan, G. A., S. C. Stirrat, and D. G. Madge. 1991.** Integrated control of light brown apple moth, *Epiphyas postvittana* (Walker), in vineyards. Wine Industry Journal 6: 220-222. [PDF](#)
- Burnip, G., and D. Suckling. 1997.** Evaluation of legumes for development of leafroller-free orchard understoreys., pp. 420-424, Proceedings of the 50th New Zealand Plant Protection Conference. New Zealand Plant Protection Society, Rotorua, New Zealand. [PDF](#)
- CAB. 2003.** Crop protection compendium: global module. Commonwealth Agricultural Bureau International, Wallingford, UK.
- Charles, J., V. White, and M. Cornwell. 1987.** Leafroller (Lepidoptera: Tortricidae) damage to buds of raspberry canes in New Zealand. New Zealand Journal of Experimental Agriculture 15: 491-496. [PDF](#)
- Charles, J., J. Walker, and V. White. 1996.** Leafroller phenology and parasitism in Hawke's Bay, New Zealand, canefruit gardens. New Zealand Journal of Crop and Horticultural Science 24: 123-131. [PDF](#)
- Cross, J. V. 1996.** A pheromone trap survey of tortricid moths (Lepidoptera: Tortricidae) in apple orchards in England subject to different insecticide management. The Entomologist 115: 168-180.

- Danthanarayana, W. 1975.** The bionomics, distribution and host range of the light brown apple moth, *Epiphyas postvittana* (Walk.) (Tortricidae). Australian Journal of Zoology 23: 419-437.
- Danthanarayana, W. 1983.** Population ecology of the light brown apple moth, *Epiphyas postvittana* (Lepidoptera: Tortricidae). Journal of Animal Ecology 52: 1-33. [PDF](#)
- Danthanarayana, W., H. Gu, and S. Ashley. 1995.** Population growth potential of *Epiphyas postvittana*, the lightbrown apple moth (Lepidoptera: Tortricidae) in relation to diet, temperature and climate. Australian Journal of Zoology 43: 381-394. [PDF](#)
- Dentener, P., S. Alexander, P. Lester, R. Petry, J. Maindonald, and R. McDonald. 1996.** Hot air treatment for disinfestation of lightbrown apple moth and longtailed mealy bug on persimmons. Postharvest Biology and Technology 8: 143-152. [PDF](#)
- Evans, J. W. 1937.** The light-brown apple moth (*Tortrix postvittana*, Walk). The Tasmanian Journal of Agriculture 8: 1-18. [PDF](#)
- Foster, S., and S. Muggleston. 1993.** Effect of design of a sex-pheromone-baited delta trap on behavior and catch of male *Epiphyas postvittana* (Walker). Journal of Chemical Ecology 19: 2617-2633. [PDF](#)
- Foster, S., and A. Howard. 1998.** Influence of stimuli from *Camelia japonica* on ovipositional behavior of generalist herbivore *Epiphyas postvittana*. Journal of Chemical Ecology 24: 1251-1275. [PDF](#)
- Foster, S., S. Muggleston, and R. Ball. 1991.** Behavioral responses of male *Epiphyas postvittana* (Walker) to sex pheromone-baited delta trap in a wind tunnel. Journal of Chemical Ecology 17: 1449-1468. [PDF](#)
- Foster, S. P., A. J. Howard, and R. H. Ayers. 1995.** Age-related changes in reproductive characters of four species of tortricid moths. New Zealand Journal of Zoology 22: 271-280. [PDF](#)
- Geier, P., and B. Springett. 1976.** Population characteristics of Australian leafrollers (*Epiphyas* spp., Lepidoptera) infesting orchards. Australian Journal of Ecology 1: 129-144. [PDF](#)
- Geier, P., and D. Briese. 1980.** The light-brown apple moth, *Epiphyas postvittana* (Walker): 4. Studies on population dynamics and injuriousness to apples in the Australian Capital Territory. Australian Journal of Ecology 5: 63-93. [PDF](#)
- Geier, P., and D. Briese. 1981.** The light-brown apple moth, *Epiphyas postvittana* (Walker): a native leafroller fostered by European settlement., pp. 131-155. In R. Kitching and R. Jones [eds.], The Ecology of Pests. CSIRO, Melbourne, Australia. [PDF](#)
- Glenn, D., and A. Hoffmann. 1997.** Developing a commercially viable system for biological control of light brown apple moth (Lepidoptera: Tortricidae) in grapes using endemic *Trichogramma* (Hymenoptera: Trichogrammatidae). Journal of Economic Entomology 90: 370-382. [PDF](#)
- Hampson, G. F. 1863.** List of the Lepidopterous insects in the British Museum. Part XXVII. Crambites and Tortricites. British Museum of Natural History, London.
- III. 1991.** *Epiphyas postvittana* (Walker). Distribution Maps of Pests, Series A, Map No. 82 (1st revision). International Institute of Entomology/Commonwealth Agricultural Bureau., London, UK. [PDF](#)

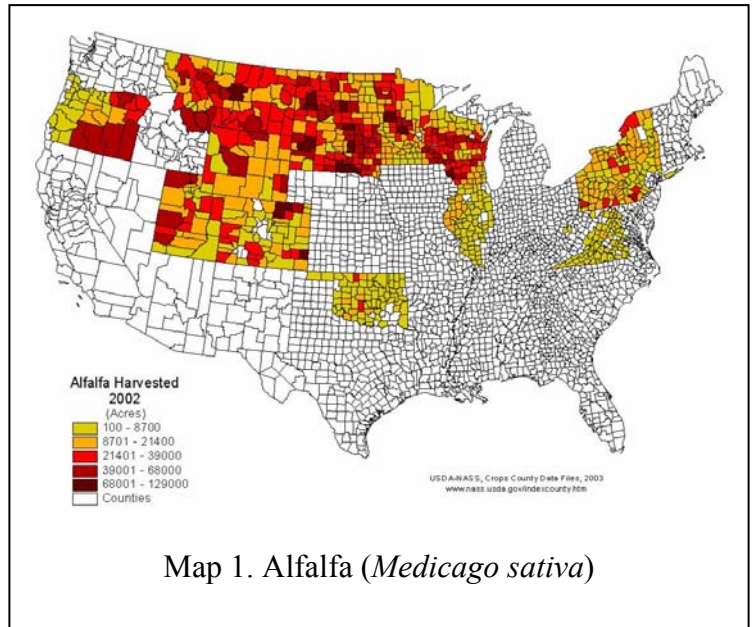
- Il'ichev, A. L., and S. P. Flett. 1999.** Major pest and disease problems in stone fruit production in Northern Victoria, Australia. Bulletin OILB-SROP 22: 131-135. [PDF](#)
- Klots, A. B. 1970.** Lepidoptera, pp. 13-18; 115-130. In S. L. Tuxen [ed.], Taxonomist's glossary of genitalia in insects. Munksgaard, Copenhagen.
- Lay-Yee, M., D. C. Whiting, and K. J. Rose. 1997.** Response of 'Royal Gala' and 'Granny Smith' apples to high-temperature controlled atmosphere treatments for control of *Epiphyas postvittana* and *Nysius huttoni*. Postharvest Biology and Technology 12: 127-136. [PDF](#)
- Lightfield, J. 1995.** Movement of litchi (*Litchi chinensis*) fruits from Hawaii into other regions of the United States: qualitative, pathway-initiated pest risk assessment. Animal and Plant Health Inspection Service, US Department of Agriculture, Riverdale, MD.
- Lo, P., and V. Murrell. 2000.** Time of leafroller infestation and effect on yield in grapes. New Zealand Plant Protection 53: 173-178. [PDF](#)
- Lo, P., V. Bohm, J. Walker, and D. Manktelow. 1995.** Monitoring pests of peaches in Hawke's Bay to reduce insecticide applications., pp. 107-110, Proceedings of the 47th New Zealand Plant Protection Conference. New Zealand Plant Protection Society. [PDF](#)
- Lo, P., D. Suckling, S. Bradley, J. Walker, P. Shaw, and G. Burnip. 2000.** Factors affecting feeding site preferences of lightbrown apple moth, *Epiphyas postvittana* (Lepidoptera: Tortricidae) on apple trees in New Zealand. New Zealand Journal of Crop and Horticultural Science 28: 235-243. [PDF](#)
- MacLellan, C. 1973.** Natural enemies of the light brown apple moth, *Epiphyas postvittana*, in the Australian Capital Territory. Canadian Entomologist 105: 681-700. [PDF](#)
- Madge, D. G., and S. C. Stirrat. 1991.** Development of a day-degree model to predict generation events for lightbrown apple moth *Epiphyas postvittana* (Walker) (Lepidoptera: Tortricidae) on grapevines in Australia. Plant Protection Quarterly 6: 39-42. [PDF](#)
- Magarey, P. A., P. R. Nicholas, and M. F. Wachtel. 1994.** Control of the diseases of grapes in Australia and New Zealand. Wine Industry Journal 9: 197-225. [PDF](#)
- McLaren, G. F., and J. A. Fraser. 1992.** Leafroller and codling moth flights in Central Otago. The Orchardist 65: 21. [PDF](#)
- Nair, N., R. Emmett, and F. Parker. 1988.** Some factors predisposing grape berries to infection by *Botrytis cinerea*. New Zealand Journal of Experimental Agriculture 16: 257-263. [PDF](#)
- Nair, N. G. 1985.** Fungi associated with bunch rot of grapes in the Hunter Valley. Australian Journal of Agricultural Research 36: 435-442.
- Nuttal, M. 1983.** *Planotortrix excessana* (Walker), *Planotortrix notophaea* (Turner), *Epiphyas postvittana* (Walker). Forest and Timber Insects of New Zealand no. 58. [PDF](#)
- Olson, D. M., E. Dinerstein, E. D. Wikramanayake, N. D. Burgess, G. V. N. Powell, E. C. Underwood, J. A. D'Amico, I. Itoua, H. E. Strand, J. C. Morrison, C. J. Loucks, T. F. Allnutt, T. H. Ricketts, Y. Kura, J. F. Lamoreux, W. W.**

- Wettengel, P. Hedao, and K. R. Kassem. 2001.** Terrestrial ecoregions of the world: a new map of life on earth. *BioScience* 51: 933-938. [PDF](#)
- Scott, R. R. 1984.** New Zealand pest and beneficial insects. Lincoln University College of Agriculture, Canterbury, New Zealand.
- Stevens, P. 1995.** Host preferences of *Trichogrammatoidea bactrae fumata* (Hym.: Trichogrammatidae) an egg parasitoid of leafrollers (Lep.: Tortricidae). *Entomophaga* 40: 379-385. [PDF](#)
- Suckling, D., and P. Shaw. 1992.** Conditions that favor mating disruption of *Epiphyas postvittana* (Lepidoptera: Tortricidae). *Environmental Entomology* 21: 949-956.
- Suckling, D., and C. Ioriatti. 1996.** Behavioral responses of leafroller larvae to apple leaves and fruit. *Entomologia Experimentalis et Applicata* 81: 97-103. [PDF](#)
- Suckling, D., P. Shaw, J. Khoo, and V. Cruickshank. 1990.** Resistance management of lightbrown apple moth, *Epiphyas postvittana* (Lepidoptera: Tortricidae) by mating disruption. *New Zealand Journal of Crop and Horticultural Science* 18: 89-98. [PDF](#)
- Suckling, D., J. Brunner, G. Burnip, and J. Walker. 1994.** Dispersal of *Epiphyas postvittana* (Walker) and *Planotortrix octo* Dugdale (Lepidoptera: Tortricidae) at a Canterbury, New Zealand orchard. *New Zealand Journal of Crop and Horticultural Science* 22: 225-234. [PDF](#)
- Suckling, D., G. Burnip, A. Gibb, J. Daly, and K. Armstrong. 2001.** Plant and host effects on the leafroller parasitoid *Dolichogenidia tasmanica*. *Entomologia Experimentalis et Applicata* 100: 253-260. [PDF](#)
- Suckling, D., G. Burnip, J. Walker, P. Shaw, G. McLaren, C. Howard, P. Lo, V. White, and J. Fraser. 1998.** Abundance of leafrollers and their parasitoids on selected host plants in New Zealand. *New Zealand Journal of Crop and Horticultural Science* 26: 193-203. [PDF](#)
- Takahashi, G. 2002.** Notes on the light brown apple moth, *Epiphyas postvittana* (Walker) intercepted at import plant quarantine of Narita Airport in Japan. *Research Bulletin of the Plant Protection Service, Japan* 38: 99-103. [PDF](#)
- Terauds, A. 1977.** Two methods of assessing damage to apples caused by light brown apple moth, *Epiphyas postvittana* (Walker). *Journal of Australian Entomological Society* 16: 367-369. [PDF](#)
- Thomas, W. 1989.** *Epiphyas postvittana* (Walker), lightbrown apple moth (Lepidoptera: Tortricidae), pp. 187-195. In P. Cameron, R. Hill, J. Bain and W. Thomas [eds.], *A review of biological control of invertebrate pests and weeds in New Zealand 1874 - 1987*. DSIR Entomology Division, Wallingford, UK. [PDF](#)
- Thomas, W. P. 1975.** Additional notes on leaf rollers. *Orchardist of New Zealand* 48: 354-355. [PDF](#)
- Thomas, W. P., and P. W. Shaw. 1982.** An attempt to control the light brown apple moth, *Epiphyas postvittana* (Walk.) (Lepidoptera: Tortricidae) by male removal, pp. 71-78. In R. A. Galbreath [ed.], *Insect pheromones and their application*. Entomology Division, DSIR, Auckland, New Zealand. [PDF](#)
- Thwaite, W. 1976.** Effect of reduced dosage of azinphos-methyl on control of codling moth, *Cydia pomonella* (L.) and light-brown apple moth, *Epiphyas postvittana* (Walk.), in an apple orchard. *Zeitschrift für Angewandte Entomologie* 80: 94-102. [PDF](#)

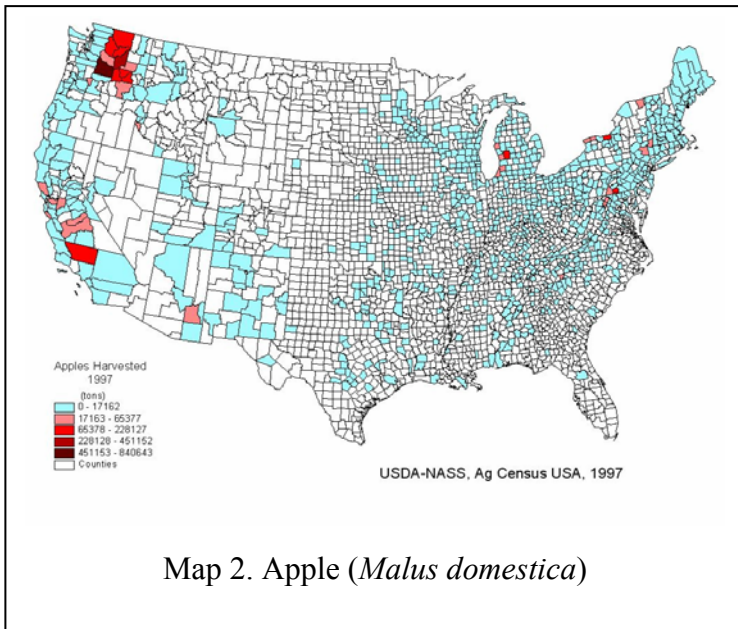
- Tomkins, A., D. Penman, and R. Chapman. 1989.** Effect of temperature and host plant on development of three species of leafrollers (Lepidoptera: Tortricidae). *New Zealand Entomologist* 12: 48-54. [PDF](#)
- USDA. 1984.** Pests not known to occur in the United States or of limited distribution No. 50: Light-brown apple moth, pp. 1-12. APHIS-PPQ, Hyattsville, MD. [PDF](#)
- USDA. 2003.** Port Information Network (PIN-309): quarantine status database. US Department of Agriculture, Animal and Plant Health Inspection Service, Plant Protection and Quarantine, Riverdale, MD. restricted access database.
- van Den Broek, W. 1975.** The effect of temperature on damage to stored apples by the light-brown apple moth, *Epiphyas postvittana* (Walker), and the effect of cold storage on its viability. *Journal of the Australian Entomological Society* 14: 1-5. [PDF](#)
- Whiting, D., and L. Hoy. 1997.** Mortality response of lightbrown apple moth to a controlled atmosphere cold storage treatment for apricots., pp. 431-435, Proceedings of the 50th New Zealand Plant Protection Conference. New Zealand Plant Protection Society, Rotorua, New Zealand. [PDF](#)
- Winter, T. 1985.** A new larval food plant for *Epiphyas postvittana* (Walker) (Lepidoptera: Tortricidae) in Cornwall. *Entomologist's Gazette* 36: 1. [PDF](#)
- Zhang, B. C. 1994.** Index of economically important Lepidoptera. CAB International, Wallingford, UK.
- Zimmerman, E. C. 1978.** Insects of Hawaii: Microlepidoptera. University Press of Hawaii, Honolulu.

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.

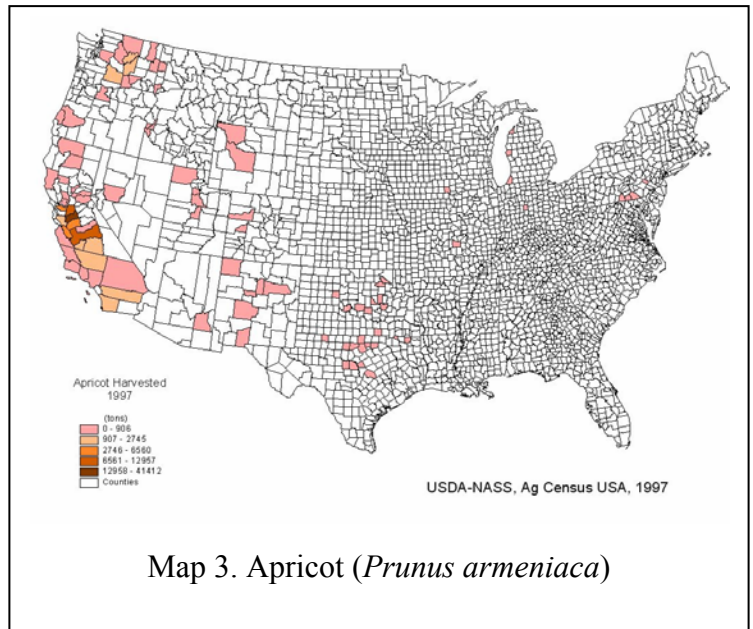
Appendix B. Commercial production of hosts of *Epiphyas postvittana* in the continental US.



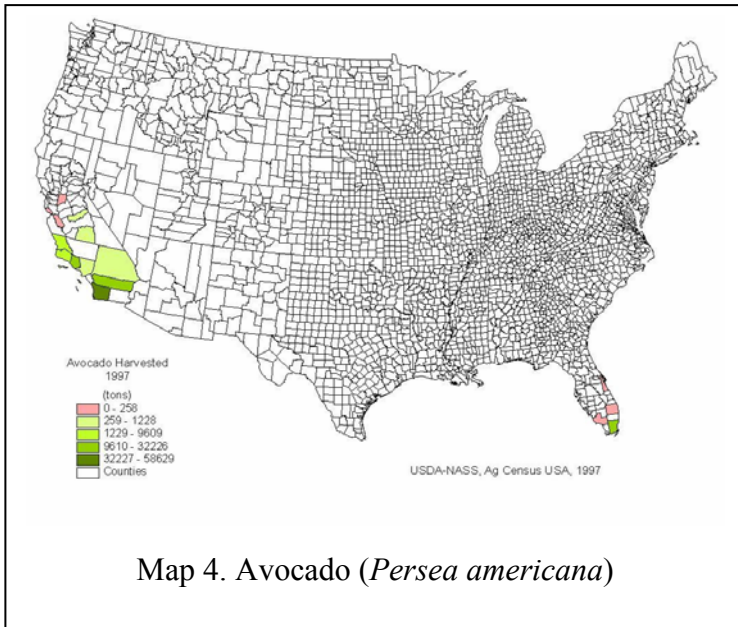
Map 1. Alfalfa (*Medicago sativa*)



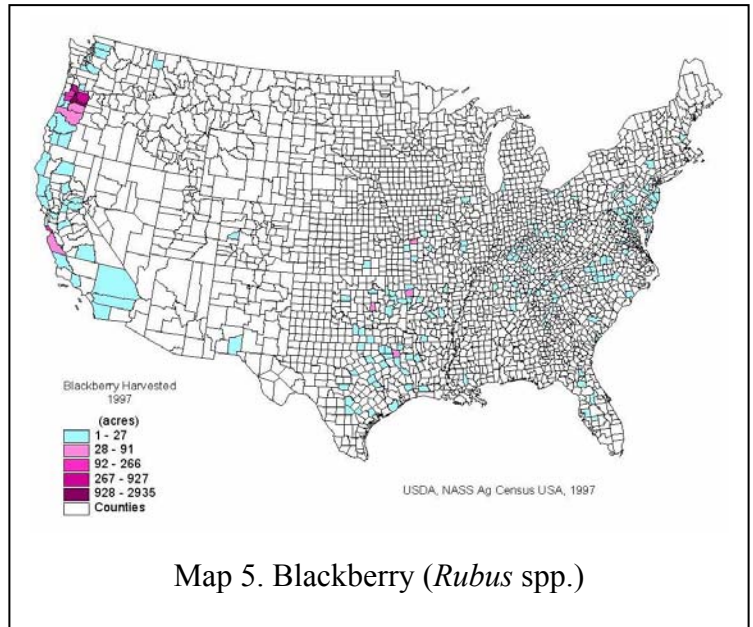
Map 2. Apple (*Malus domestica*)



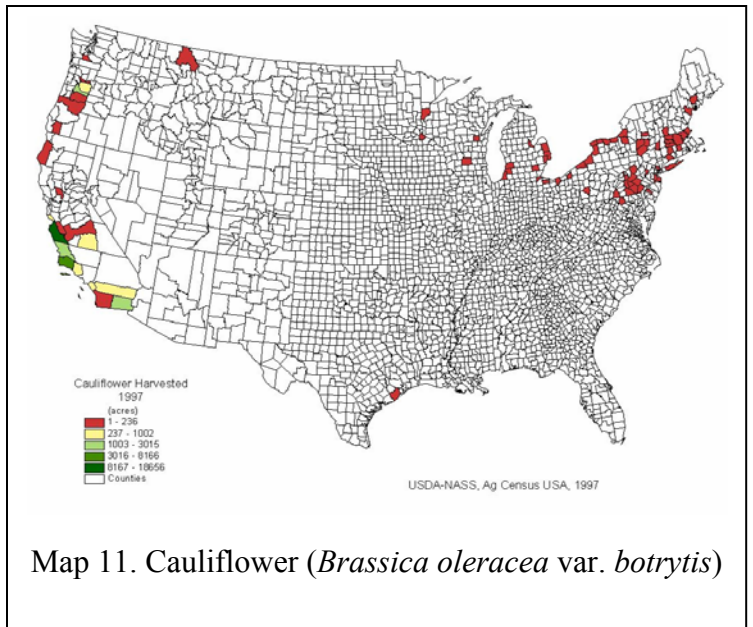
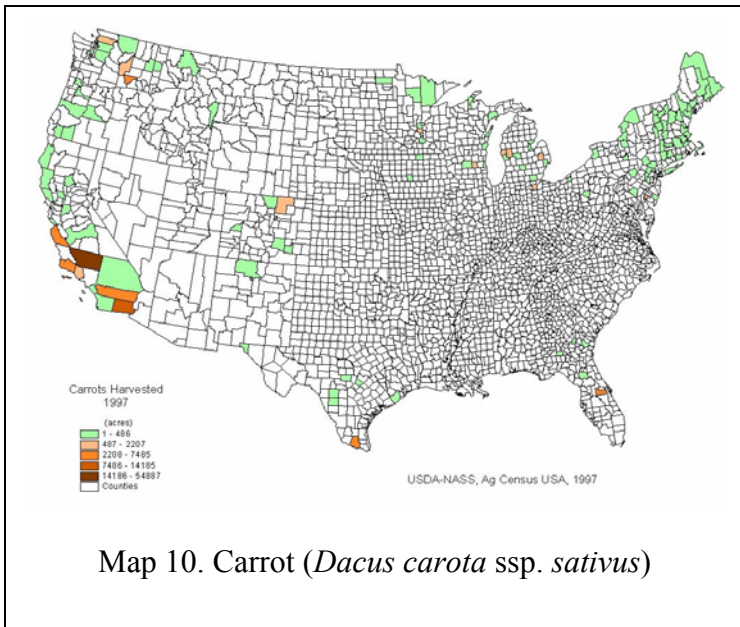
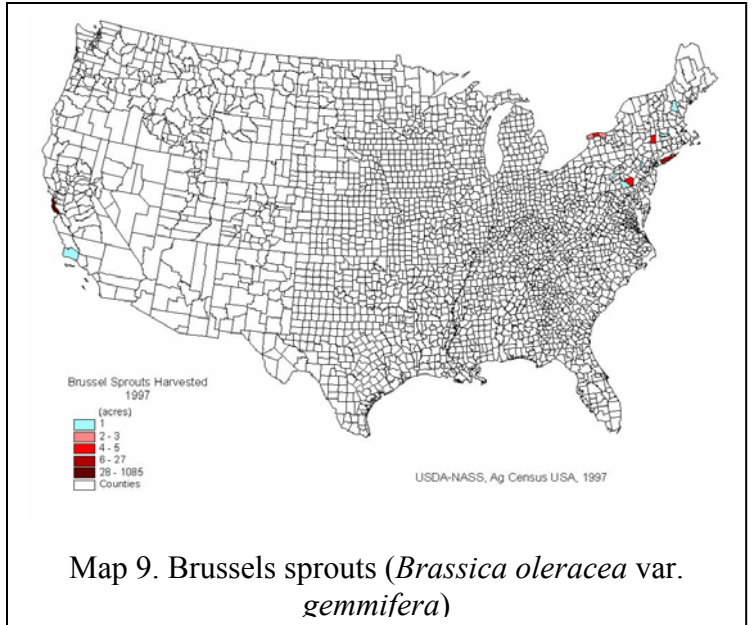
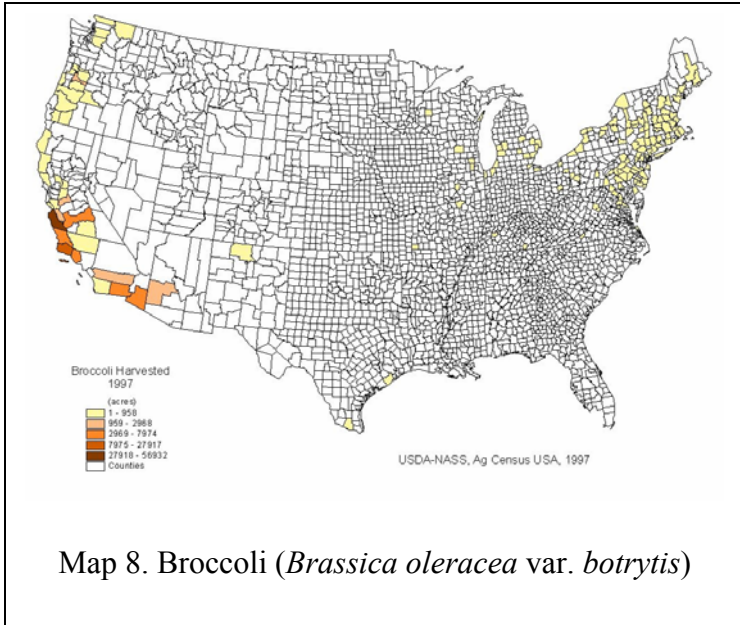
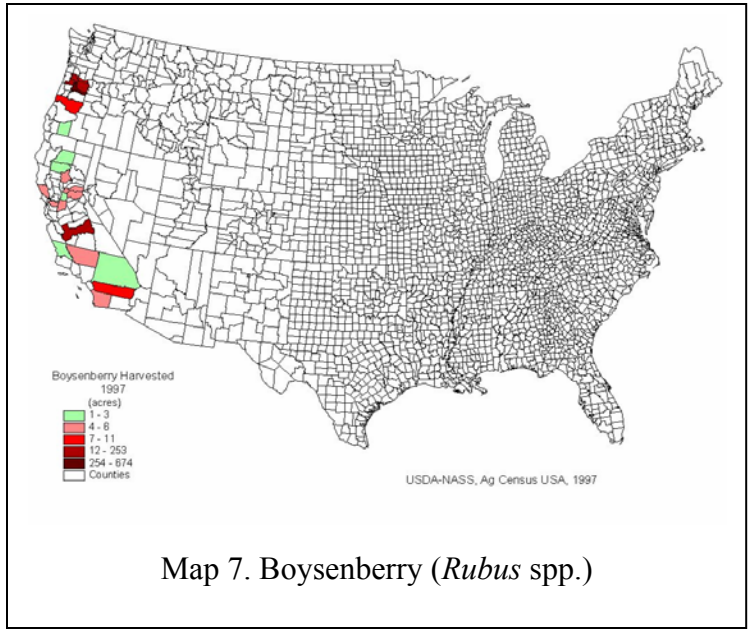
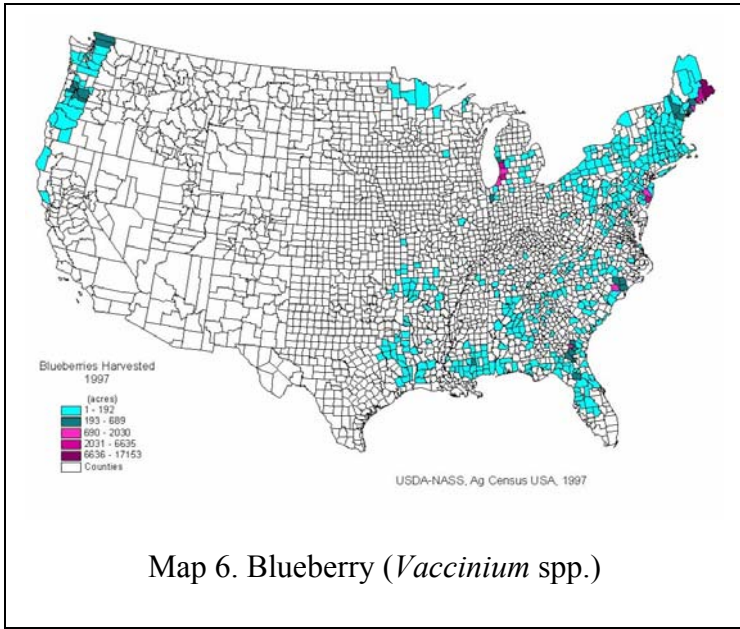
Map 3. Apricot (*Prunus armeniaca*)

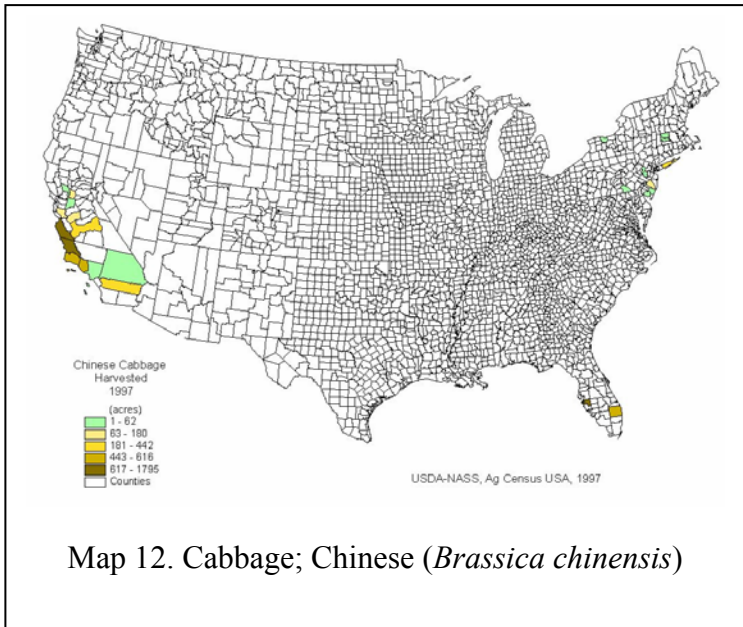


Map 4. Avocado (*Persea americana*)

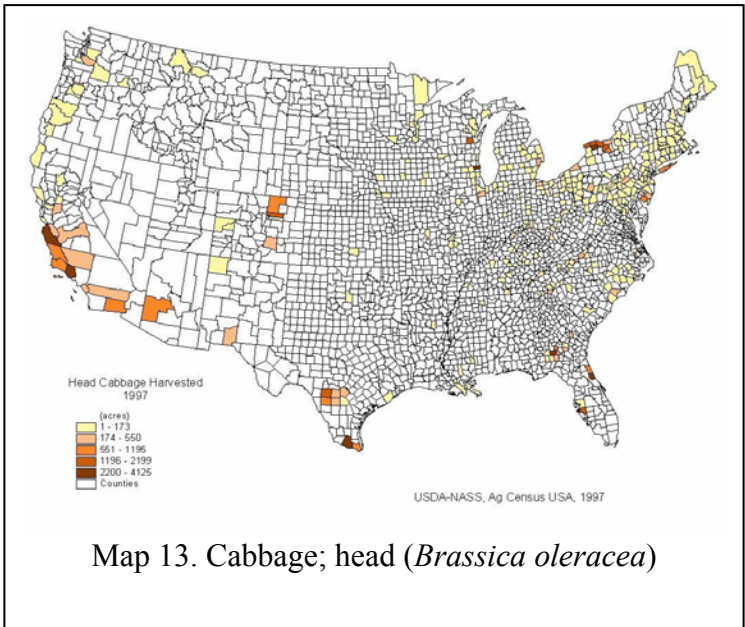


Map 5. Blackberry (*Rubus* spp.)

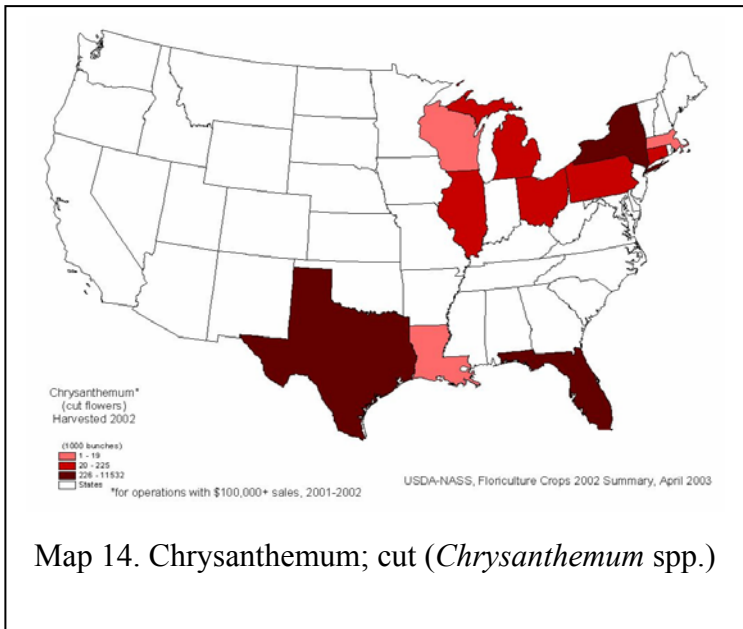




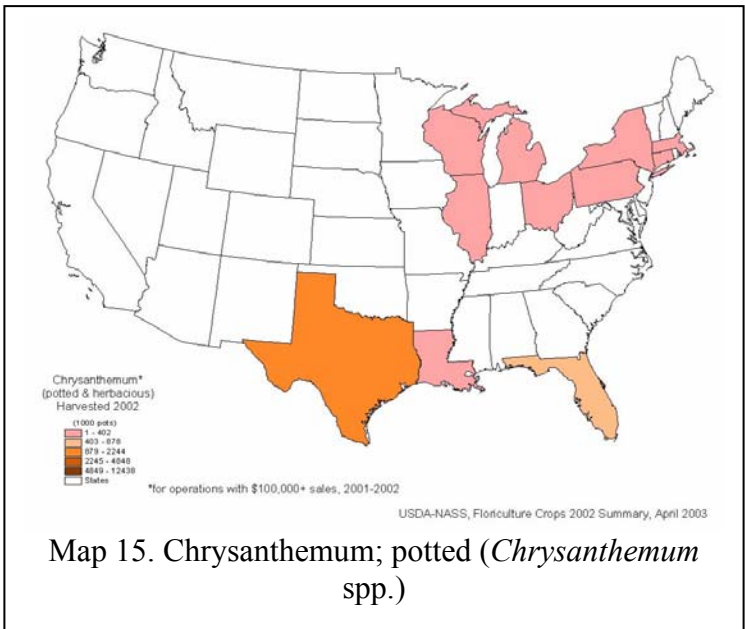
Map 12. Cabbage; Chinese (*Brassica chinensis*)



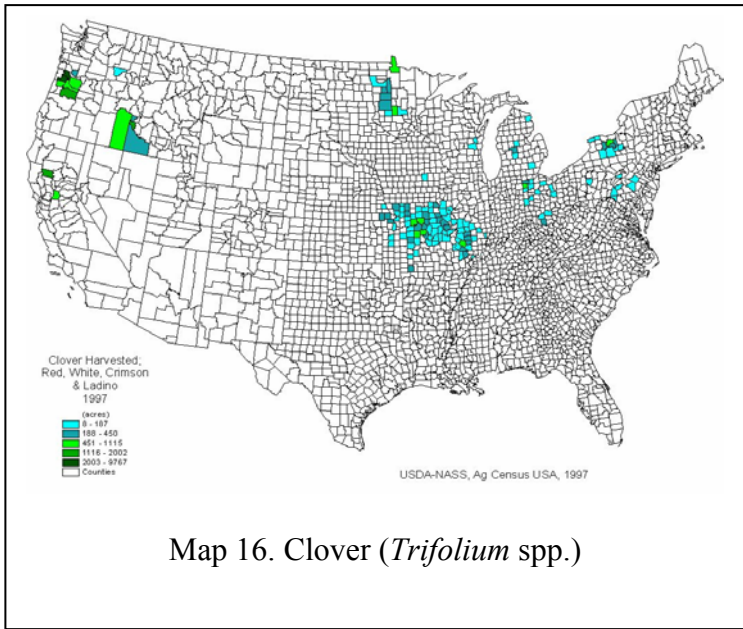
Map 13. Cabbage; head (*Brassica oleracea*)



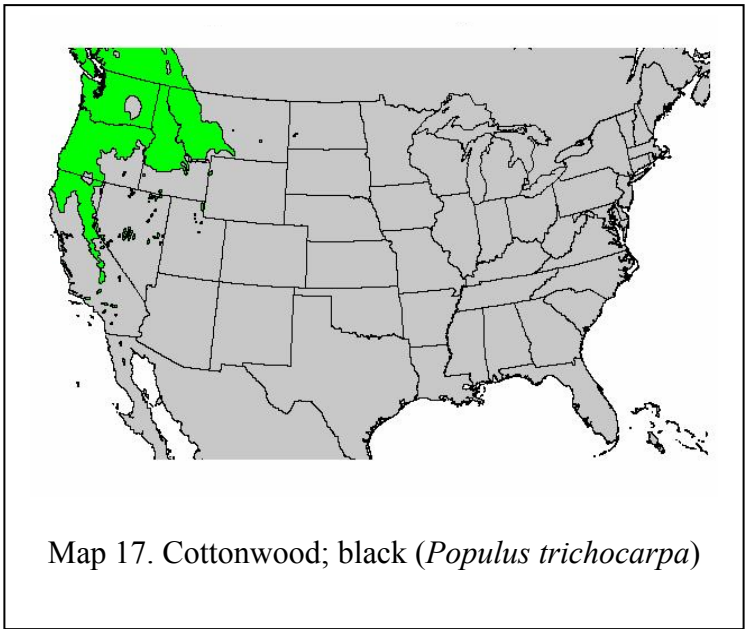
Map 14. Chrysanthemum; cut (*Chrysanthemum* spp.)



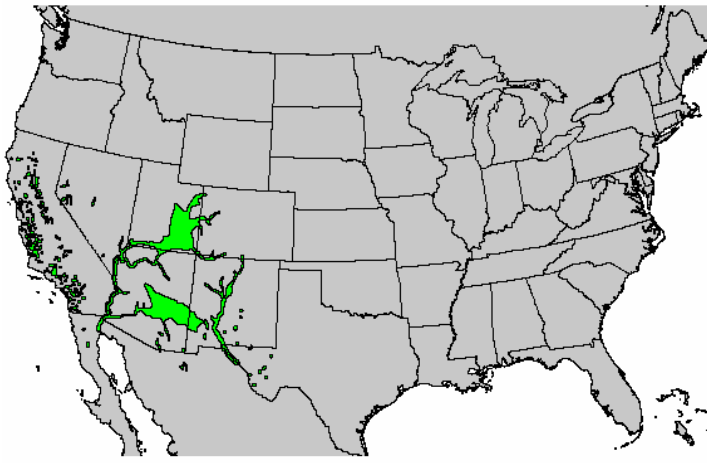
Map 15. Chrysanthemum; potted (*Chrysanthemum* spp.)



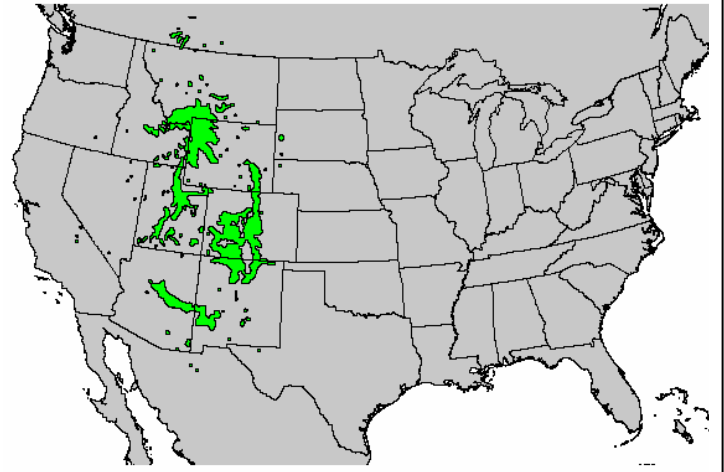
Map 16. Clover (*Trifolium* spp.)



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



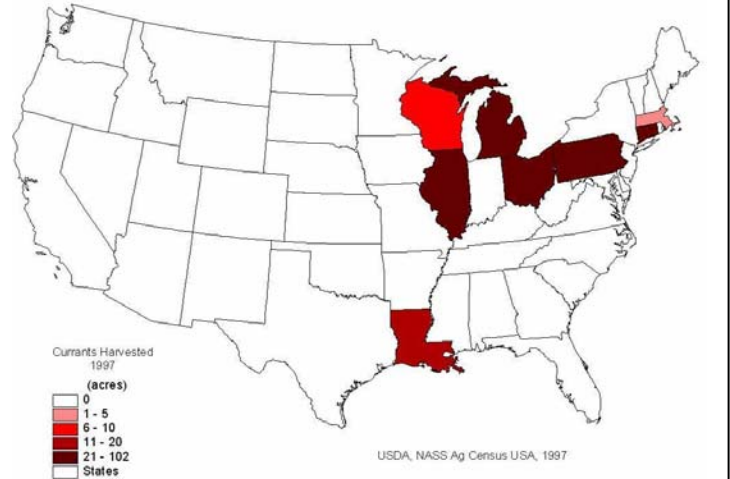
Map 18. Cottonwood-fremont (*Populus fremontii*)



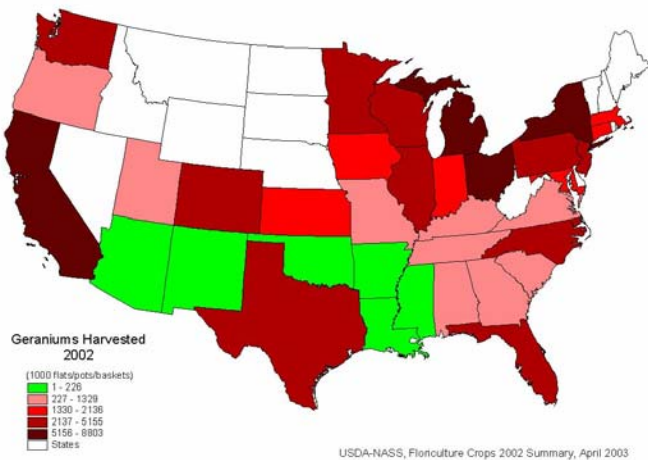
Map 19. Cottonwood-narrowleaf (*Populus angustifolia*)



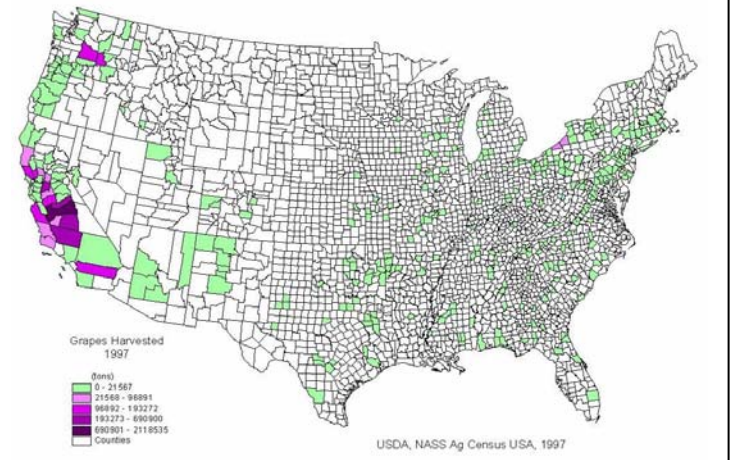
Map 20. Cottonwood; swamp (*Populus heterophylla*)



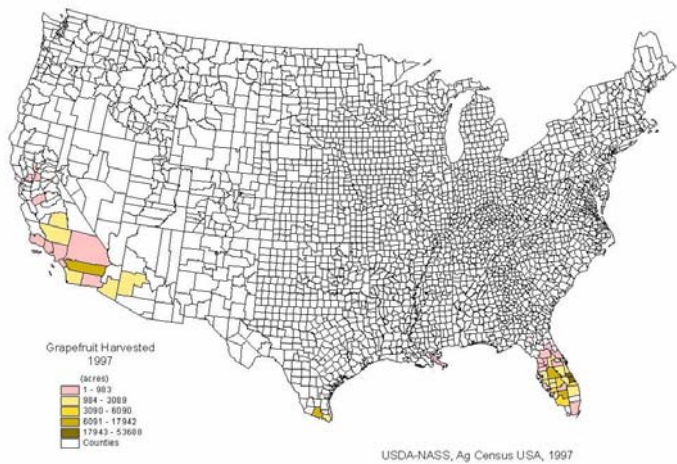
Map 21. Curren (*Ribes* spp.)



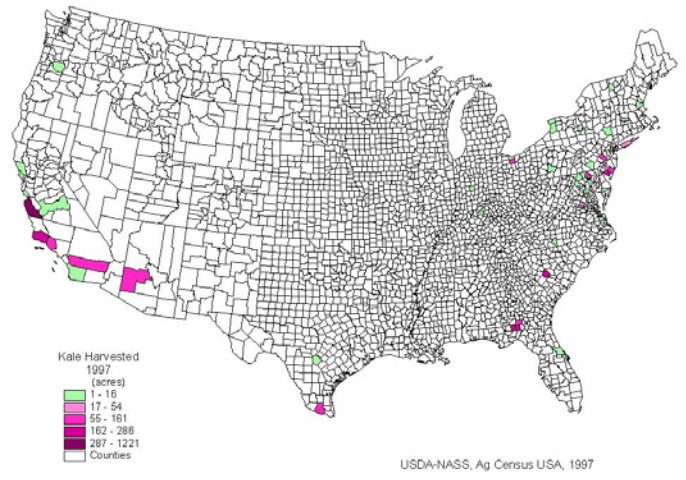
Map 22. Geranium (*Pelargonium* spp.)



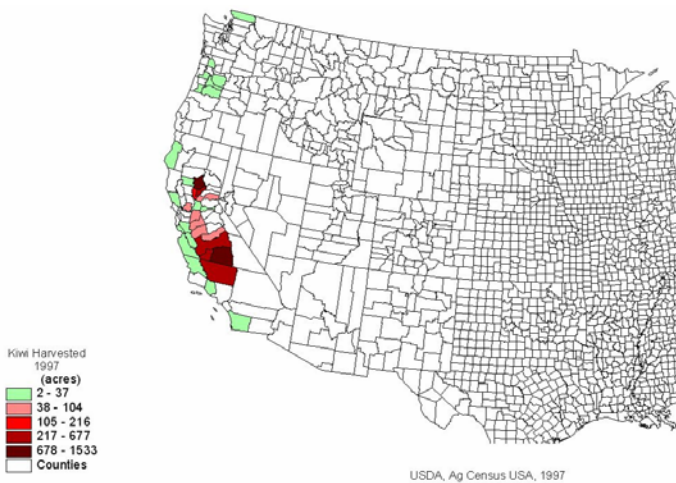
Map 23. Grape (*Vitis* spp.)



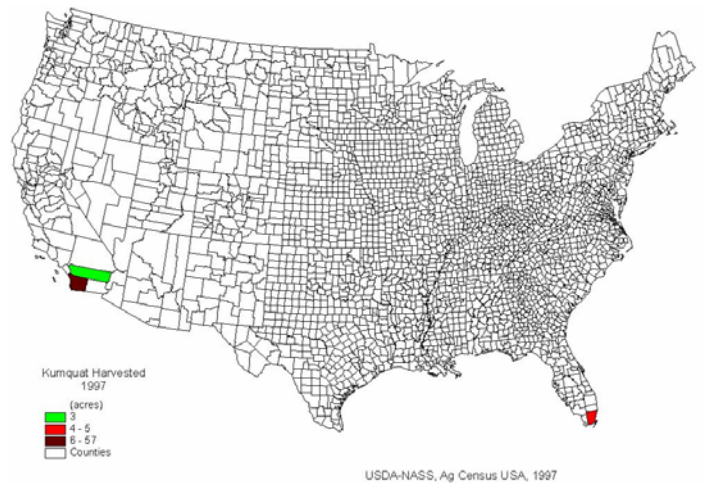
Map 24. Grapefruit (*Citrus paradiss* Mac. Fad.)



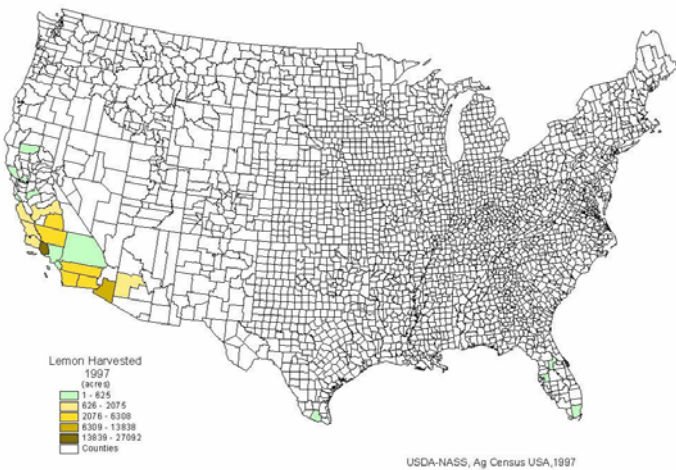
Map 25. Kale (*Brassica alboglabra* L.H. Bailey)



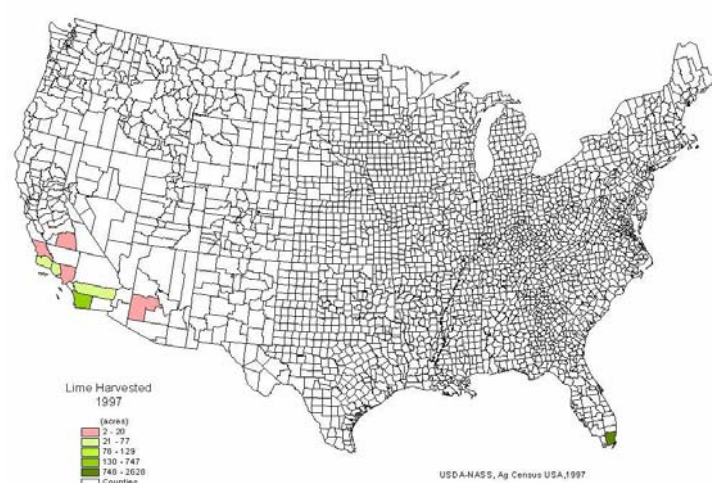
Map 26. Kiwifruit (*Actinidia chinensis*)



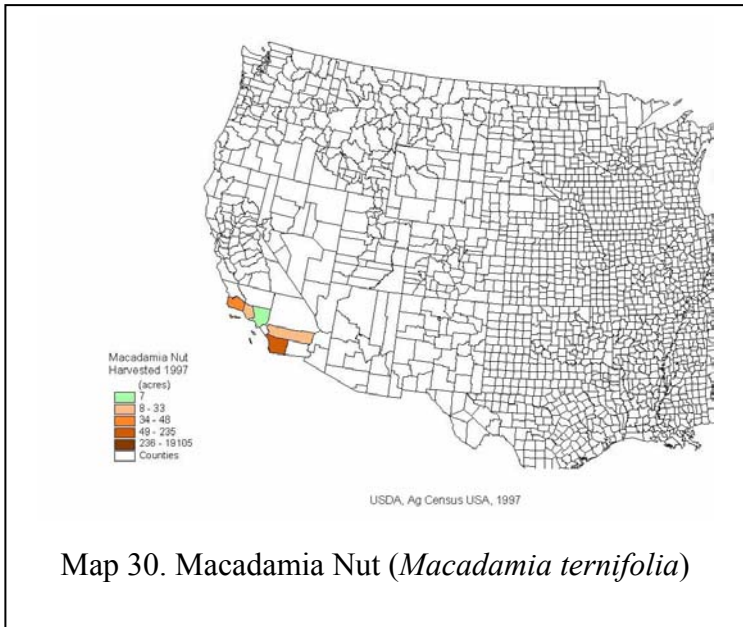
Map 27. Kumquat (*Fortunella* spp.)



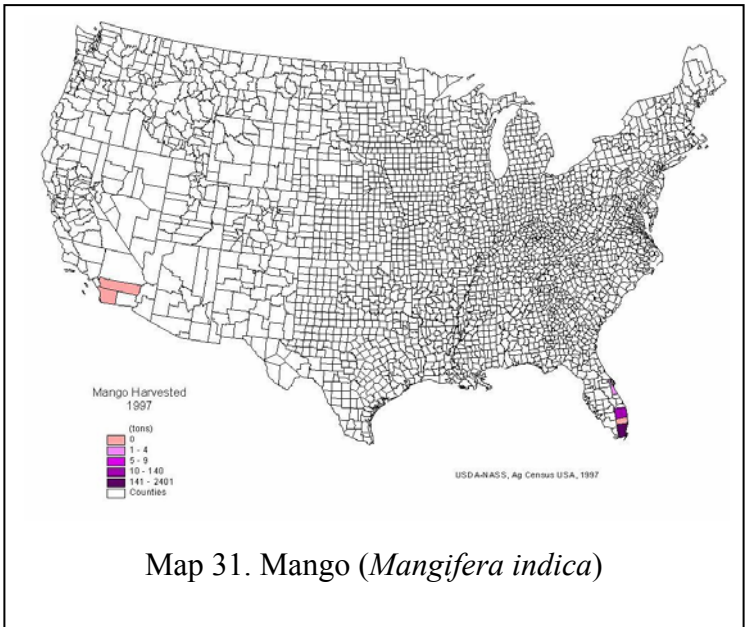
Map 28. Lemon (*Citrus limon*)



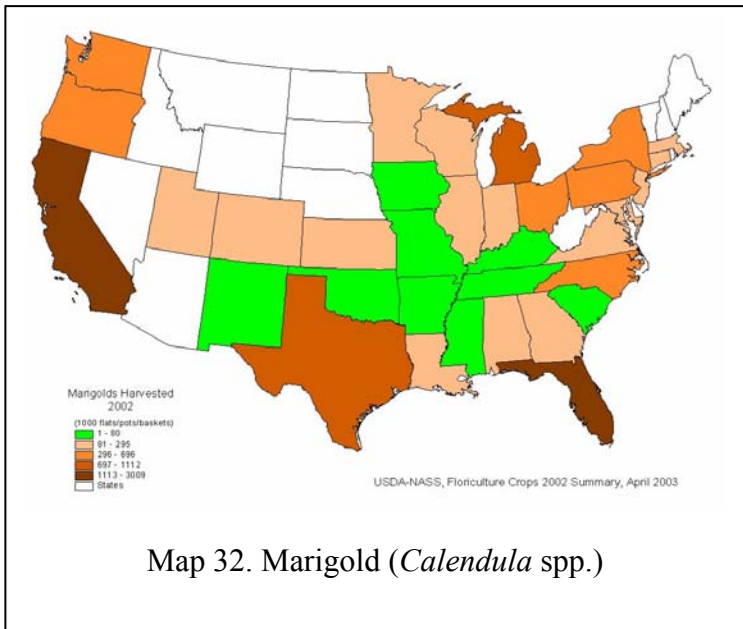
Map 29. Lime (*Citrus aurantifolia*)



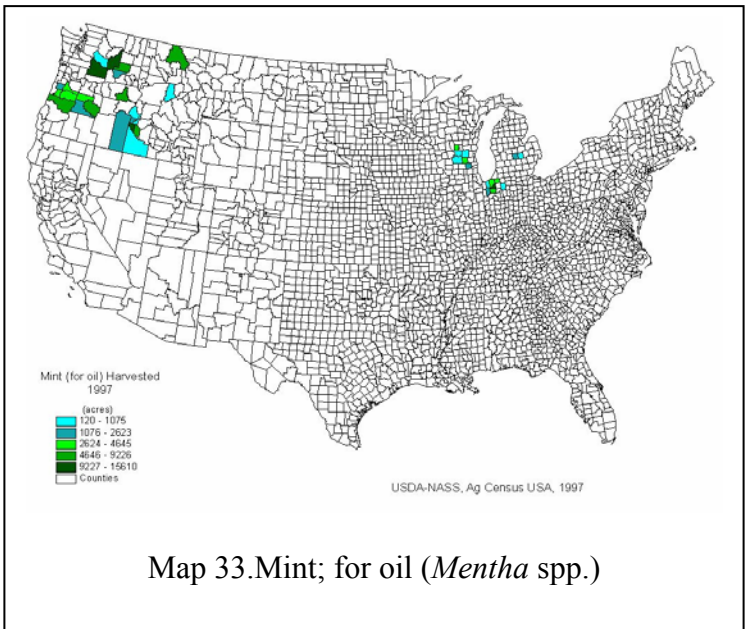
Map 30. Macadamia Nut (*Macadamia ternifolia*)



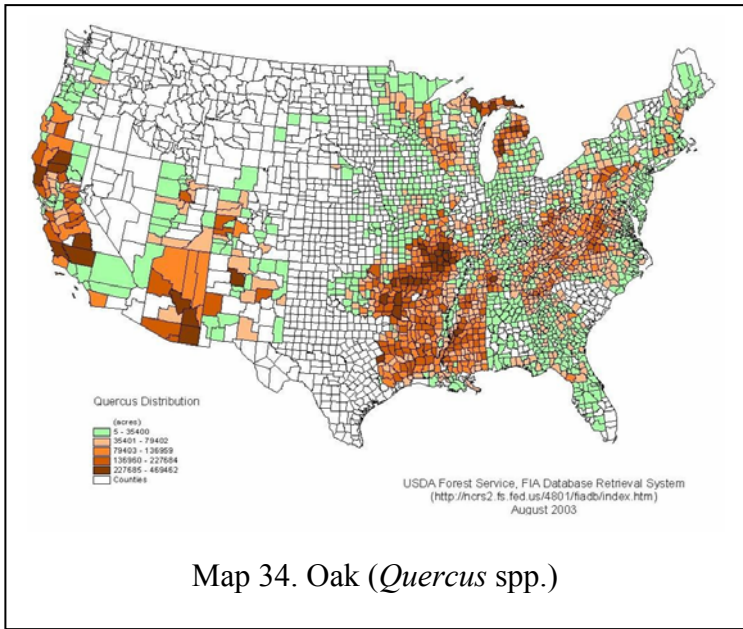
Map 31. Mango (*Mangifera indica*)



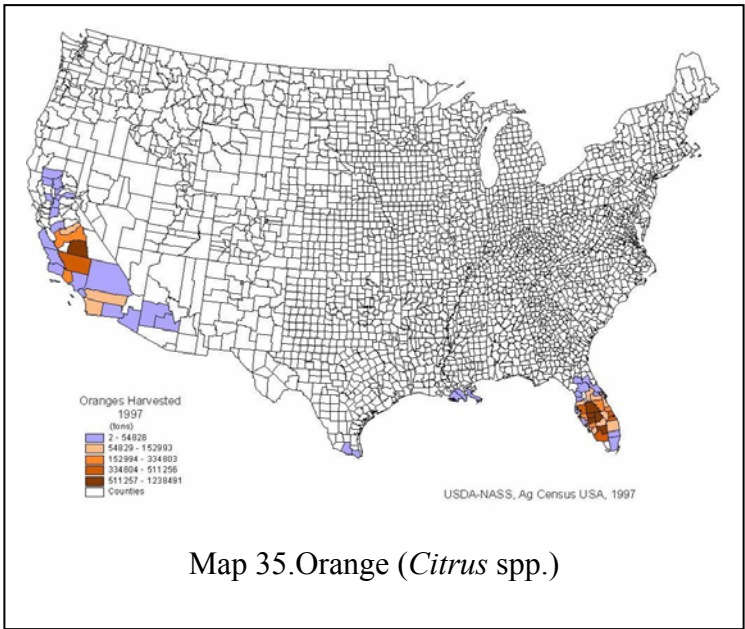
Map 32. Marigold (*Calendula* spp.)



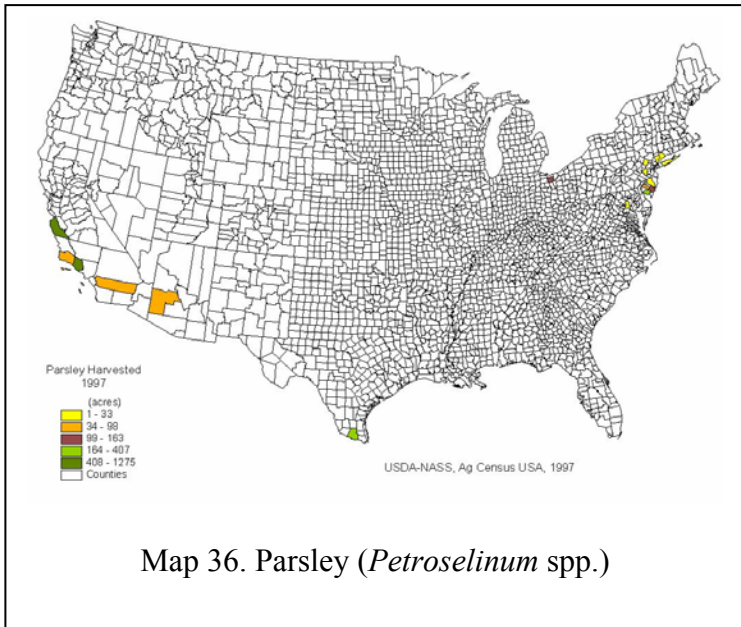
Map 33. Mint; for oil (*Mentha* spp.)



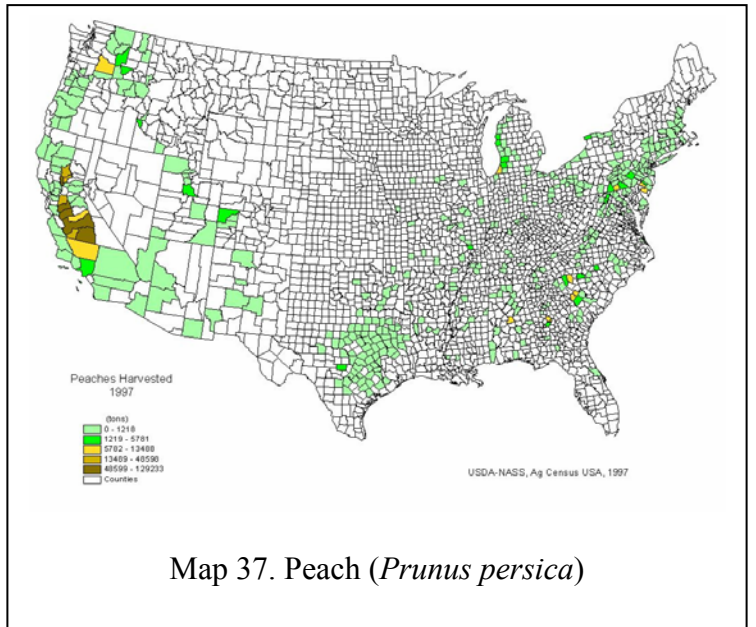
Map 34. Oak (*Quercus* spp.)



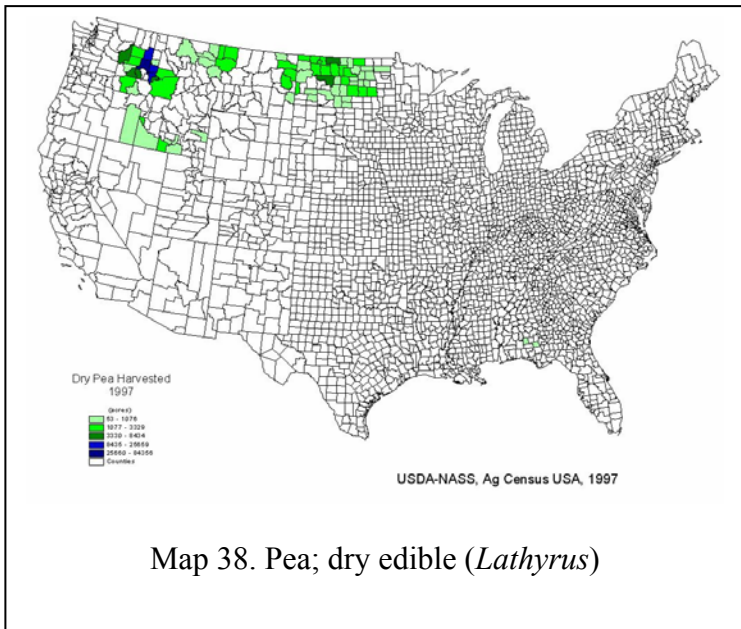
Map 35. Orange (*Citrus* spp.)



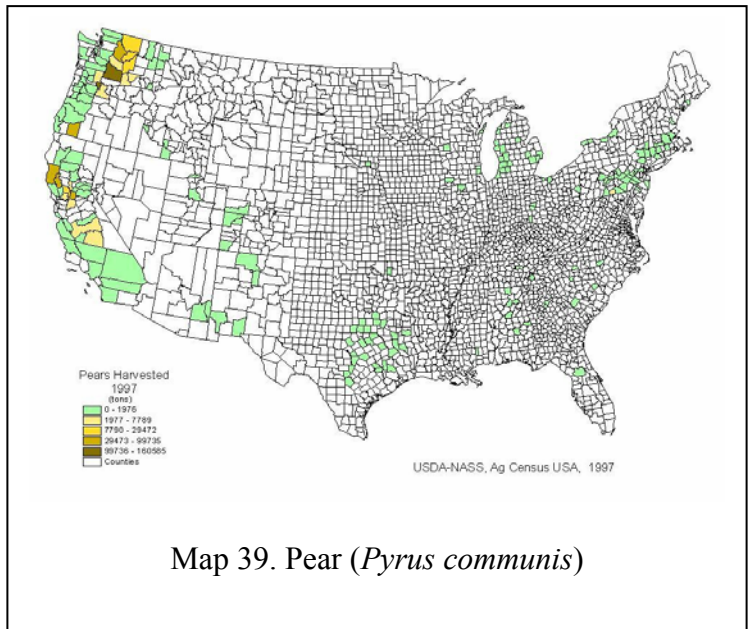
Map 36. Parsley (*Petroselinum spp.*)



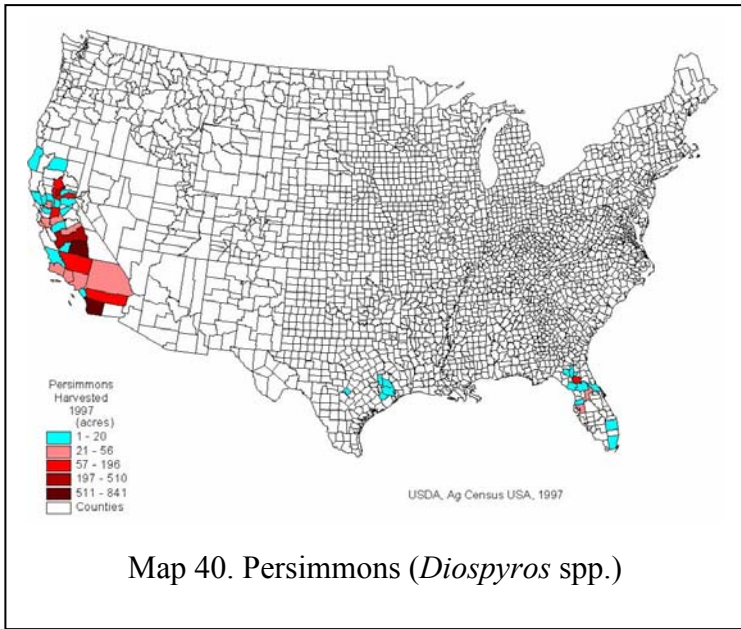
Map 37. Peach (*Prunus persica*)



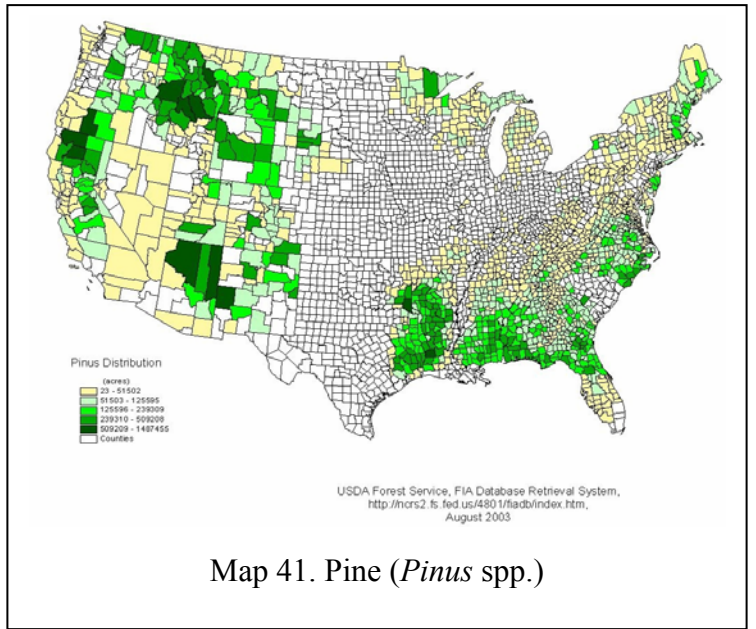
Map 38. Pea; dry edible (*Lathyrus*)



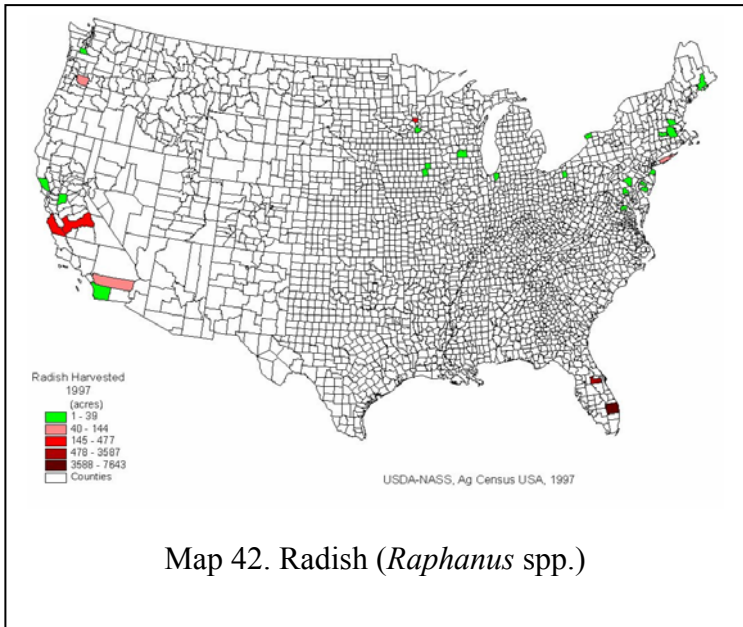
Map 39. Pear (*Pyrus communis*)



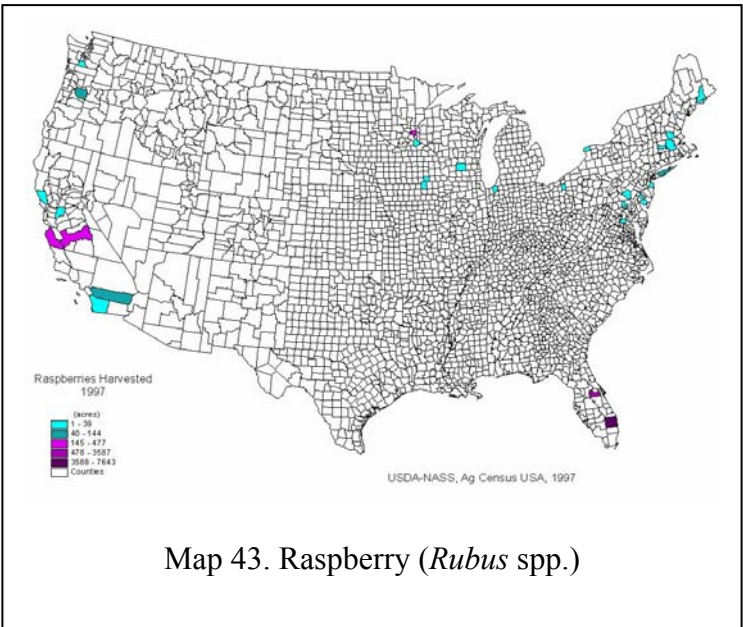
Map 40. Persimmons (*Diospyros spp.*)



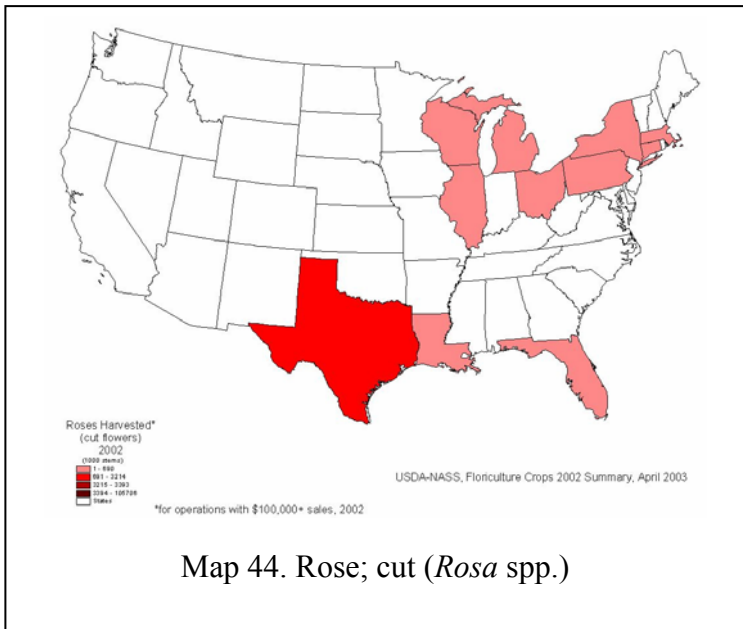
Map 41. Pine (*Pinus spp.*)



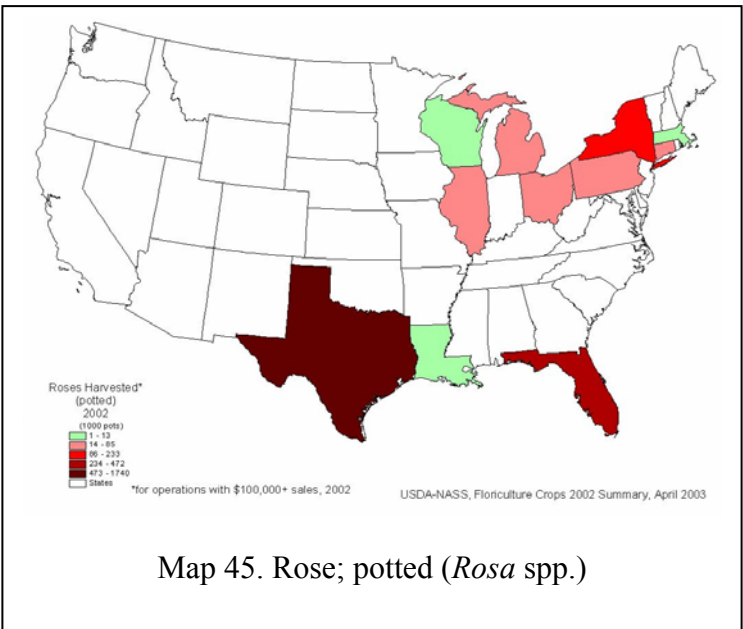
Map 42. Radish (*Raphanus* spp.)



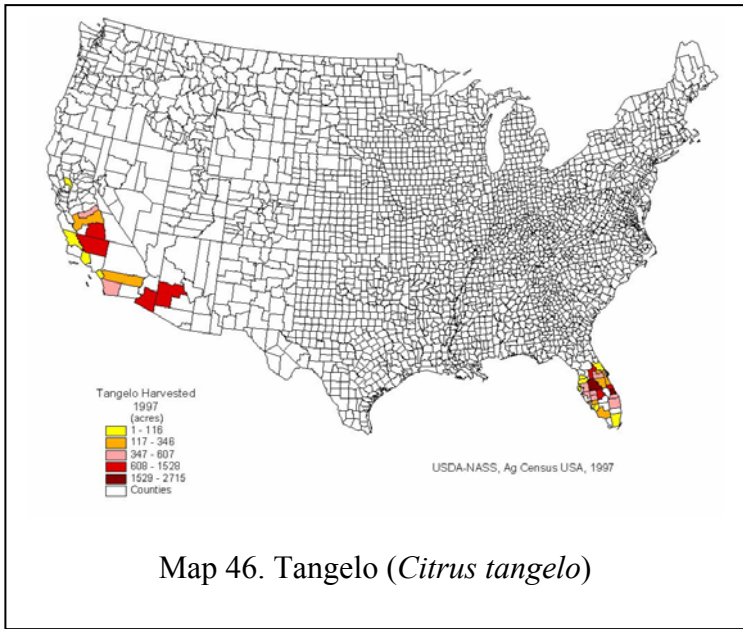
Map 43. Raspberry (*Rubus* spp.)



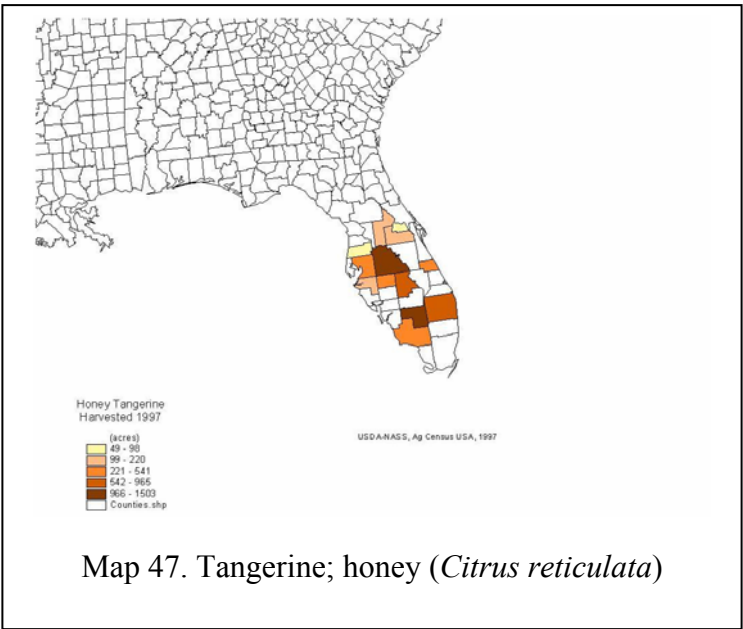
Map 44. Rose; cut (*Rosa* spp.)



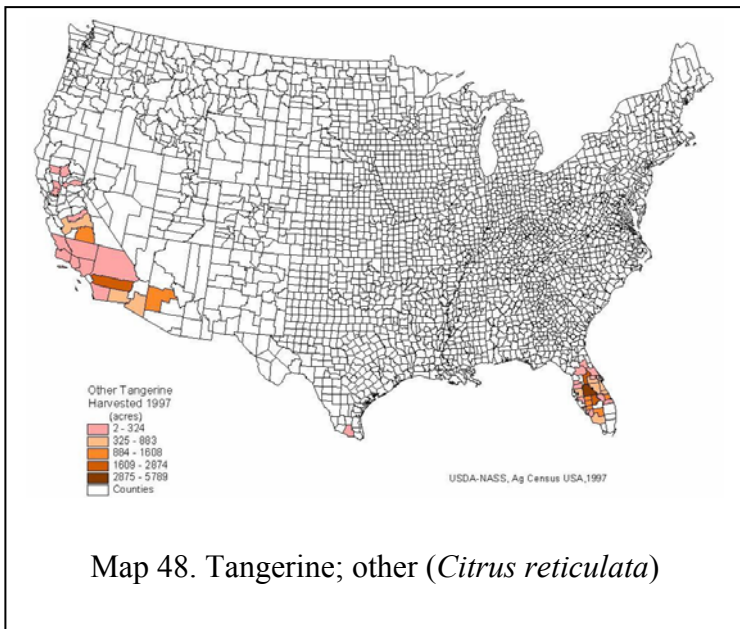
Map 45. Rose; potted (*Rosa* spp.)



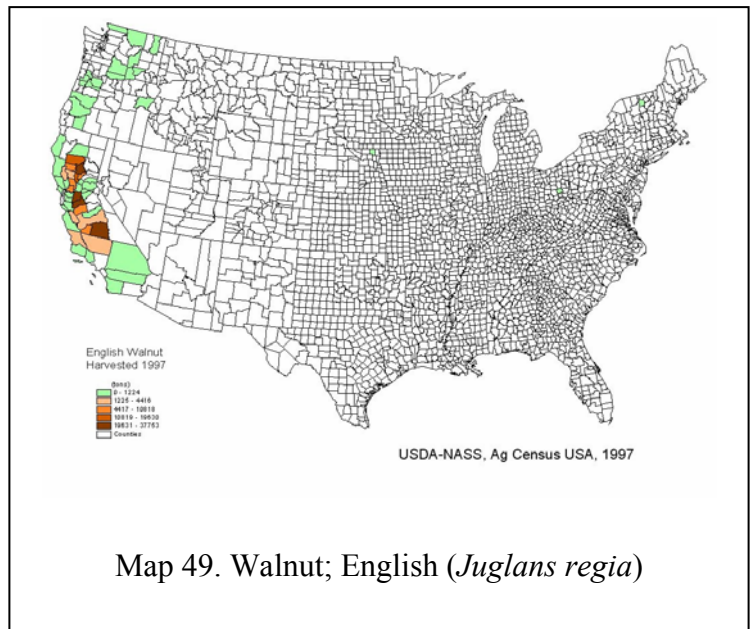
Map 46. Tangelo (*Citrus tangelo*)



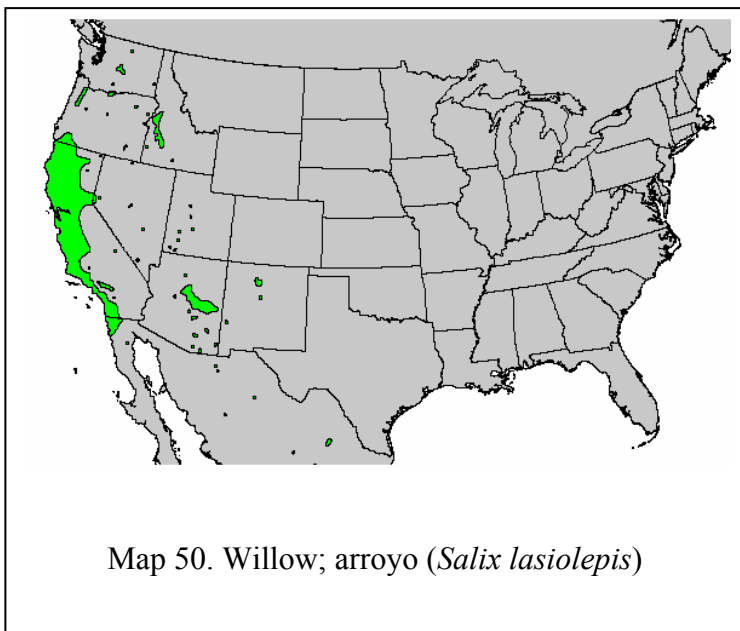
Map 47. Tangerine; honey (*Citrus reticulata*)



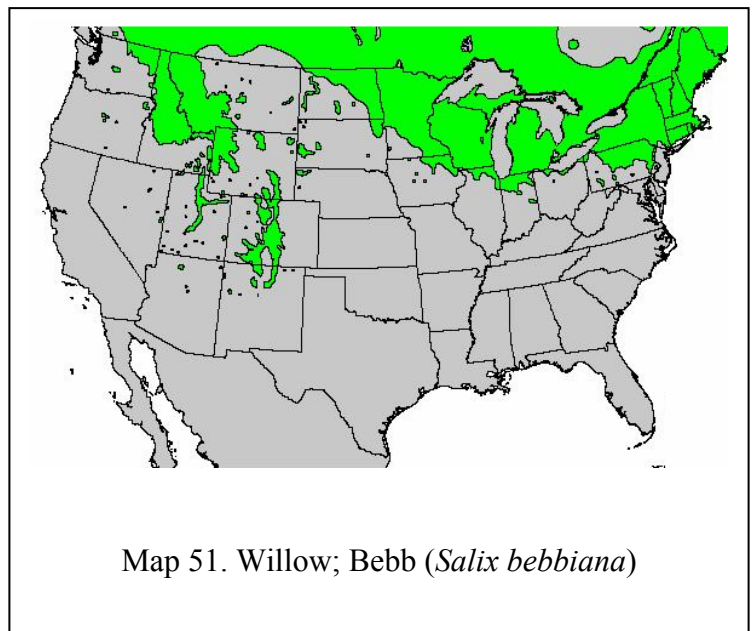
Map 48. Tangerine; other (*Citrus reticulata*)



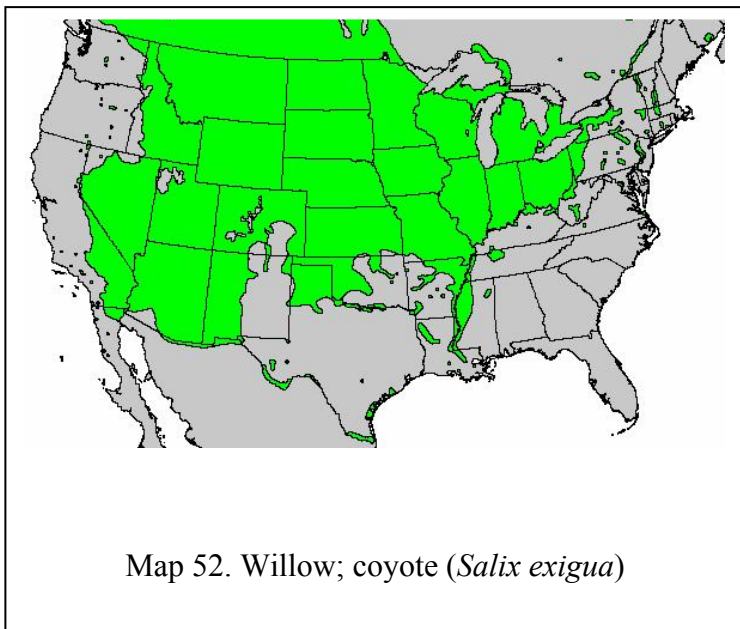
Map 49. Walnut; English (*Juglans regia*)



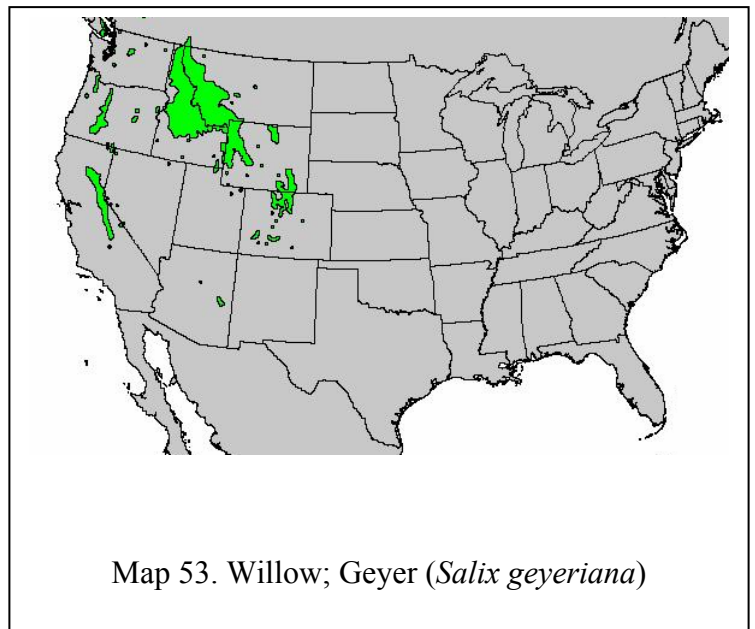
Map 50. Willow; arroyo (*Salix lasiolepis*)



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



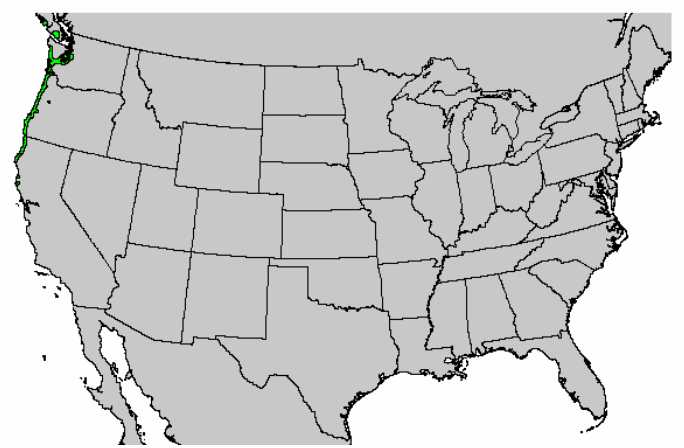
Map 52. Willow; coyote (*Salix exigua*)



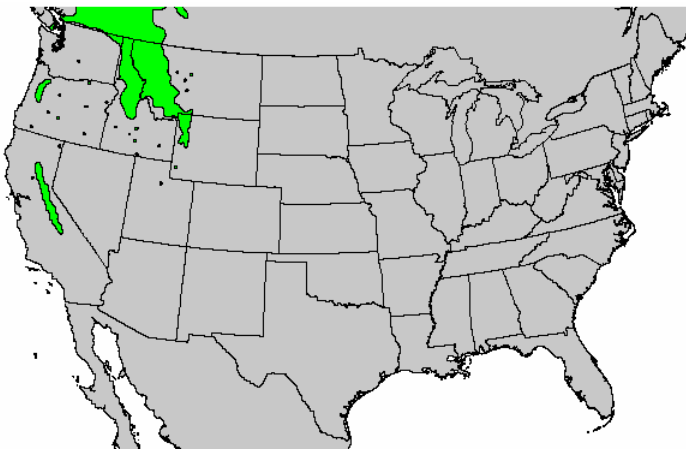
Map 53. Willow; Geyer (*Salix geyeriana*)



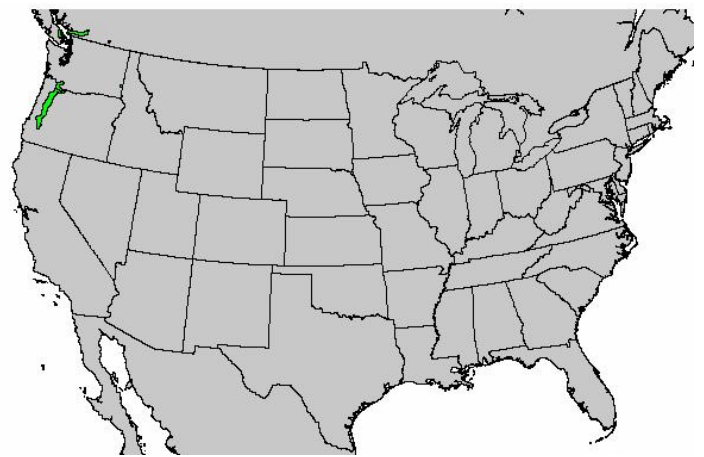
Map 54. Willow; Hinds (*Salix hindsiana*)



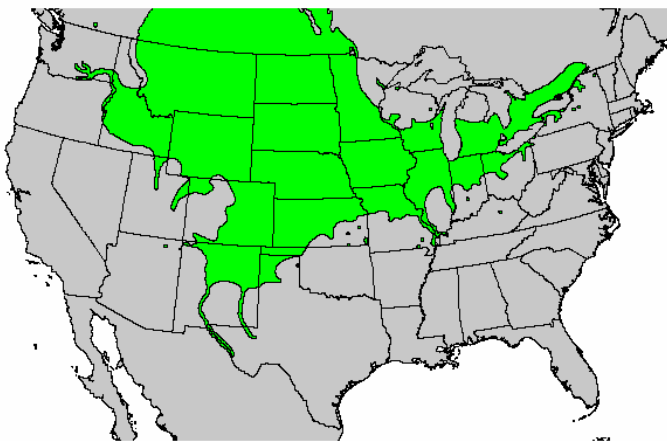
Map 55. Willow; Hooker (*Salix hookeriana*)



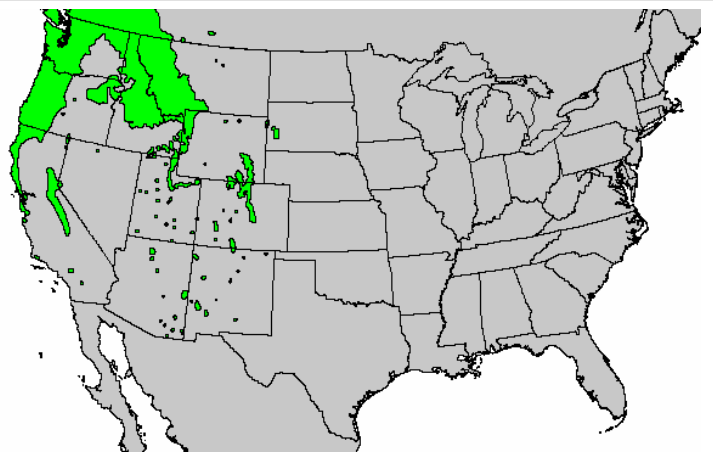
Map 56. Willow; Mackenzie (*Salix mackenzieana*)



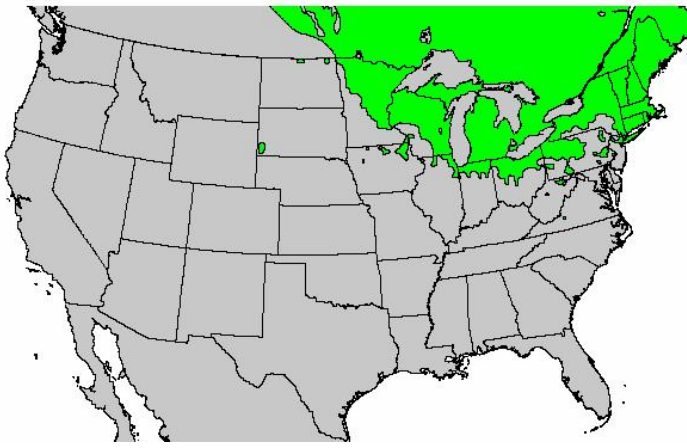
Map 57. Willow; northwest (*Salix sessilifolia*)



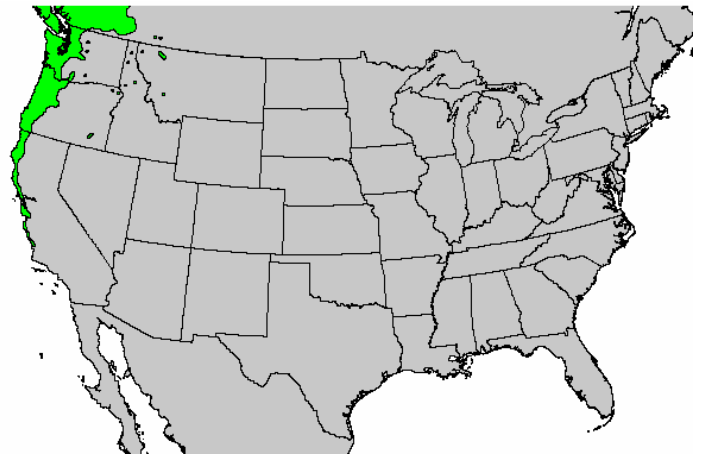
Map 58. Willow; peachleaf (*Salix amygdaloides*)



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)

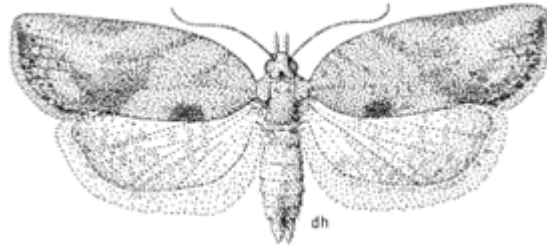


Figure C1. Sketch of *Epiphyas postvittana* adult
[image from <http://www.hortnet.co.nz/publications/hortfacts/images/hf401003.gif>]

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.
- *vicareana* 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.

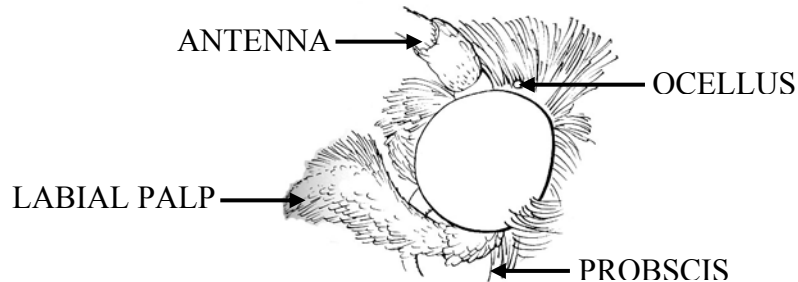


Figure C3. Lateral view of head of *Epiphyas postvittana* (Walker)-male
[Reproduced from Zimmerman (1978)]

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).

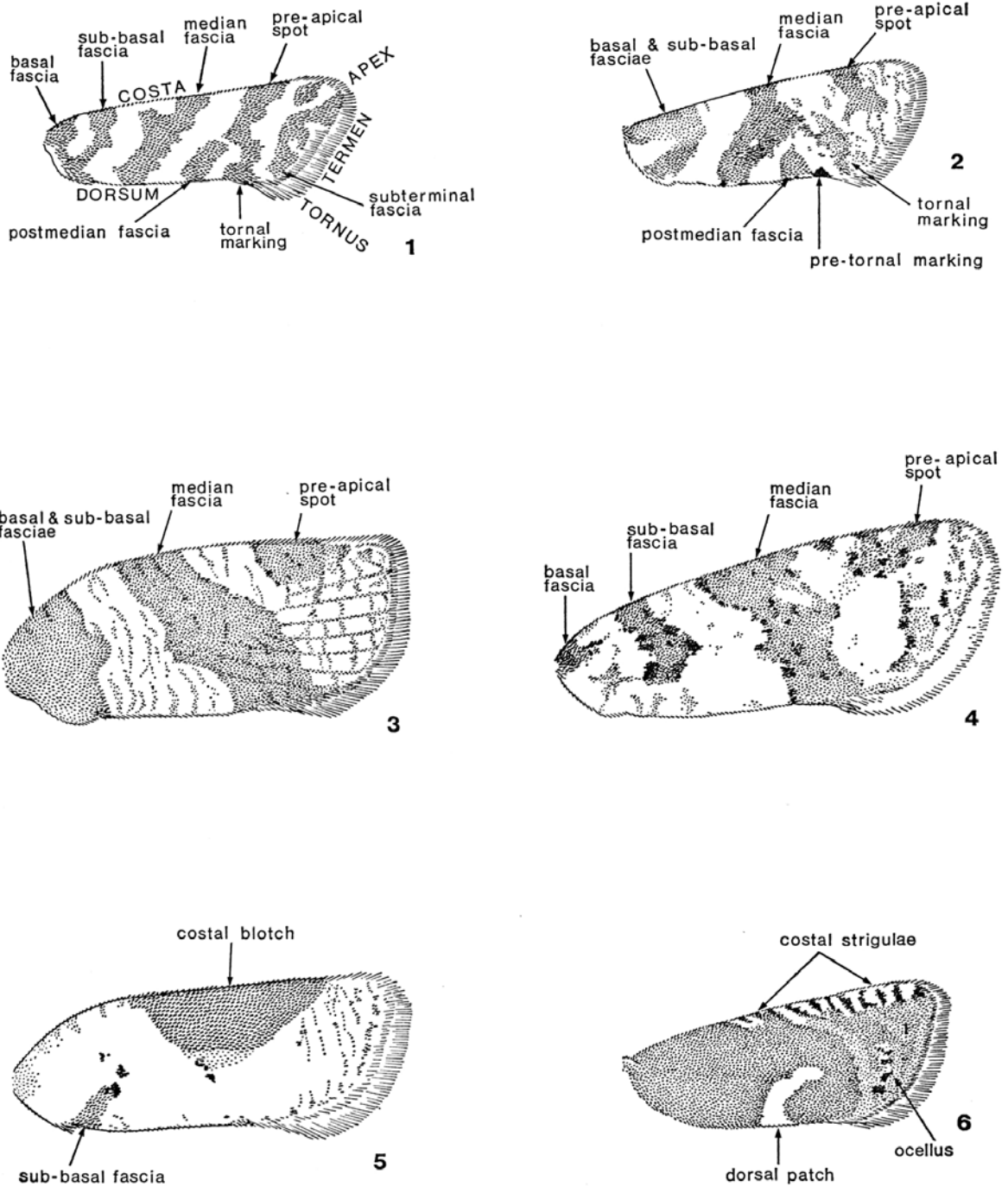


Figure. C4. Variation in wing patterns of Tortricoid moths
 [Reproduced from Bradley et al. (1979)]

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

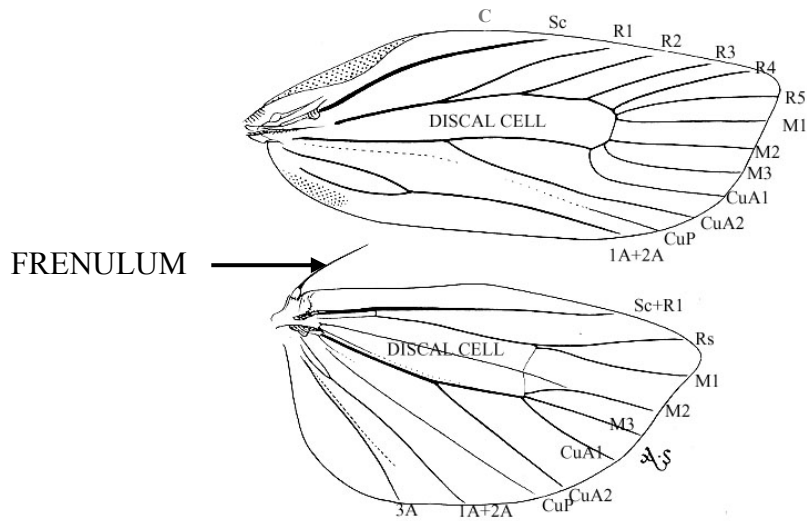


Figure C5. Wing venation of *Epiphyas postvittana* (Walker)-male. Veins: A-anal; C-Costa, Cu-Cubitus (CuA1-1st anterior cubitus; CuA2-2nd anterior cubitus; CuP-posterior cubitus); M-Media, R-Radius, Sc-Subcosta. [Reproduced from Zimmerman (1978)]

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).

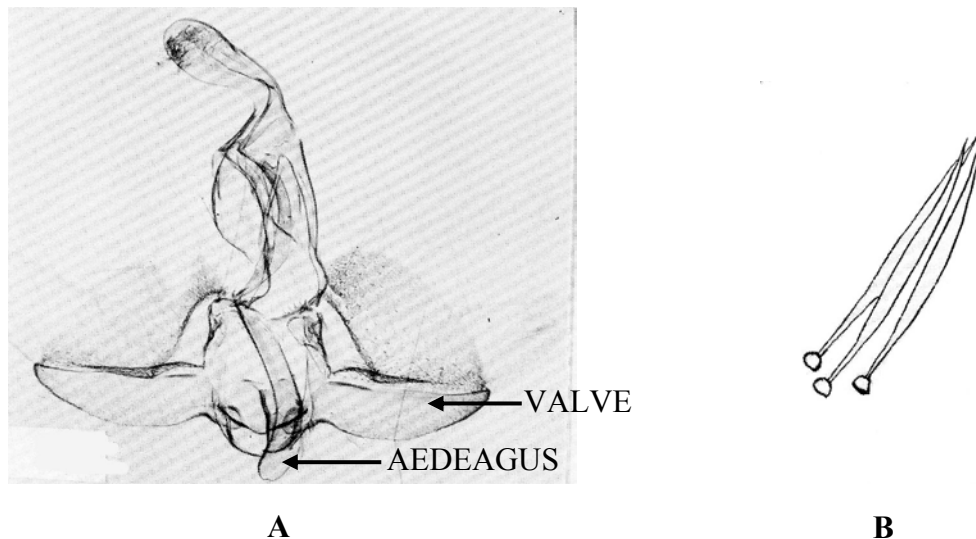


Figure C6. Ventral view of male genitalia of *Epiphyas postvittana* (Walker): A-genital capsule; B-cornuti [Reproduced from Zimmerman (1978)]

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

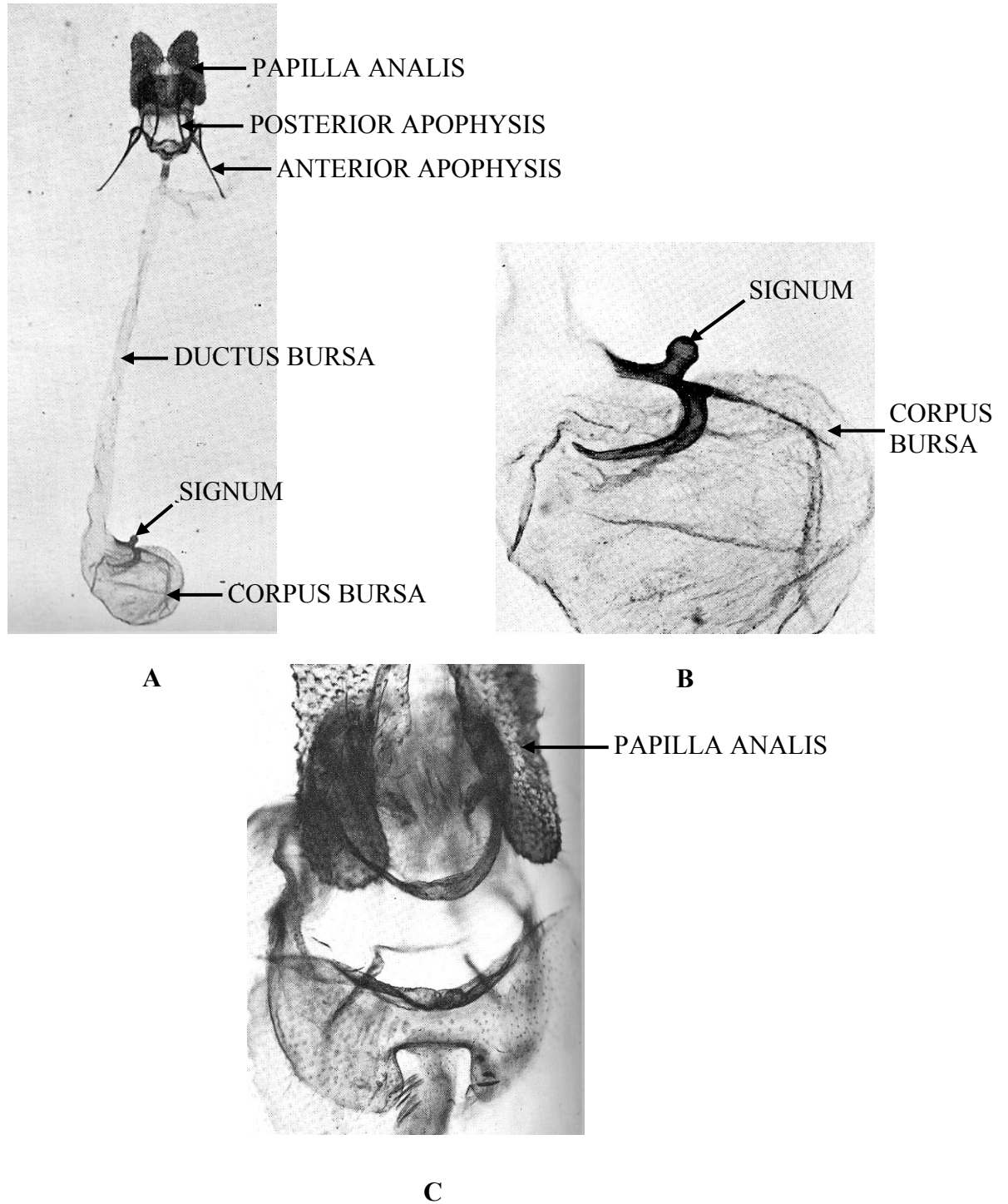


Figure C7. Female genitalia of *Epiphyas postvittana* (Walker). A-entire genitalia, B-detail corpus bursa, C-detail papillae anales and associated structures [Reproduced from Zimmerman (1978)].

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

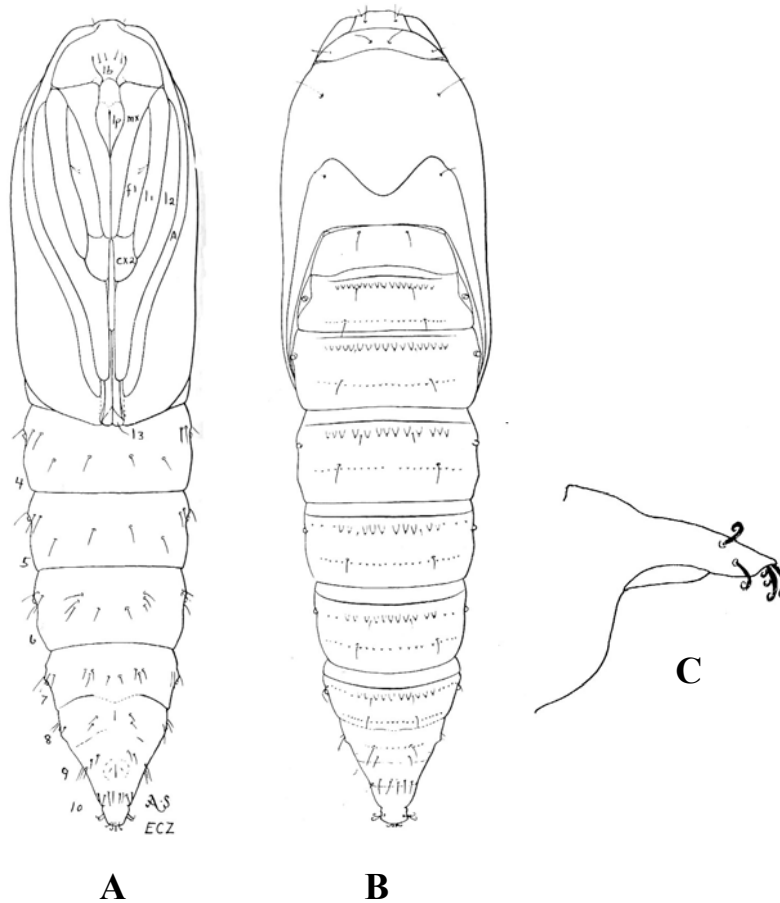


Figure C9. Pupa of *Epiphyas postvittana* (Walker): A-ventral view , B-dorsal view , C-detail lateral view left side cauda of pupa. In A: cx2-mesocoxa; f1-profemora; lb-labrum; lp-labial palpus, l1, l2, l3-legs; mx-galea of maxilla (proboscis); W2-hindwing [Reproduced from Zimmerman (1978)].

Similar species:

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

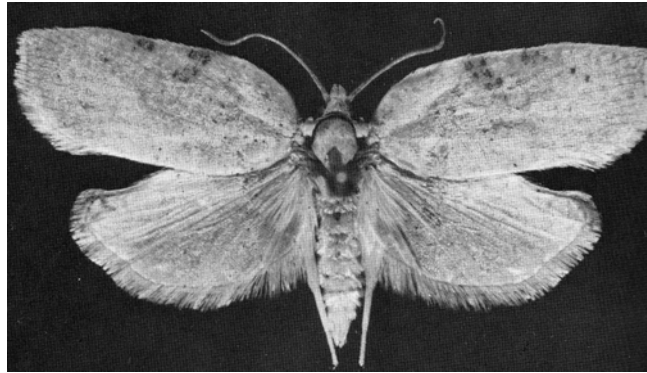


Figure C10. *Amorbia emigratella* Busck
[Reproduced from Zimmerman (1978)]

[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.

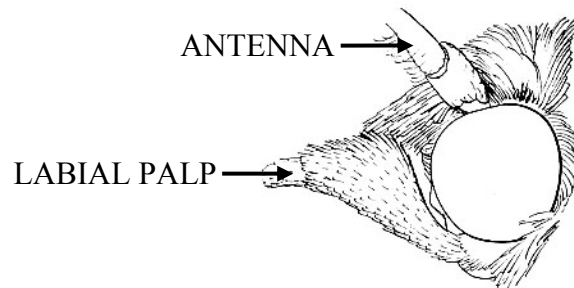


Figure C11. Lateral view of head of *Amorbia emigratella* Busck-male
[Reproduced from Zimmerman (1978)]

Venation: As in Fig. C12.

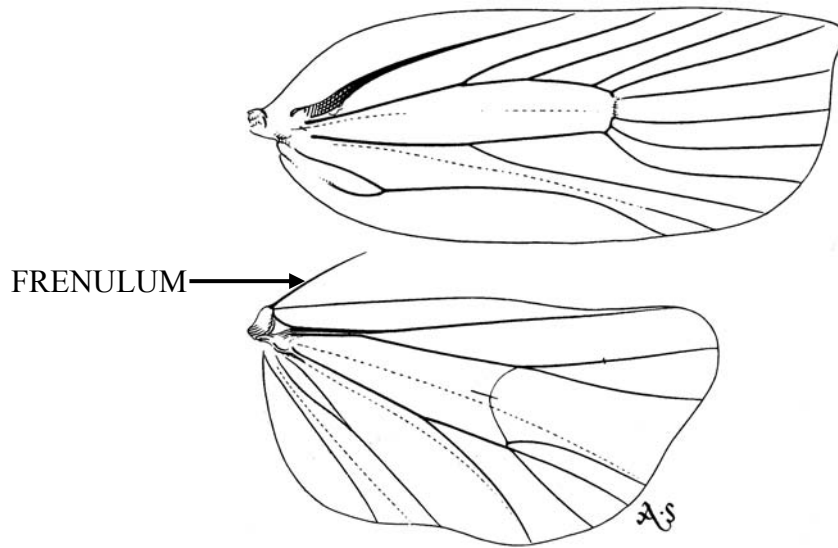


Figure C12. Venation of *Amorbia emigratella* Busck –male.
[Reproduced from Zimmerman (1978)].

Male genitalia: As in Fig. C13.

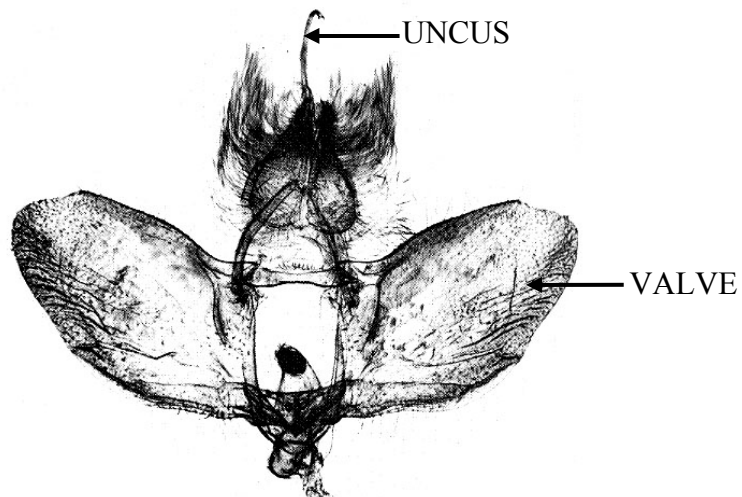


Figure C13. Ventral view male genitalia *Amorbia emigratella* Busck
[Reproduced from Zimmerman (1978)].

Female genitalia: As in Fig. C14.

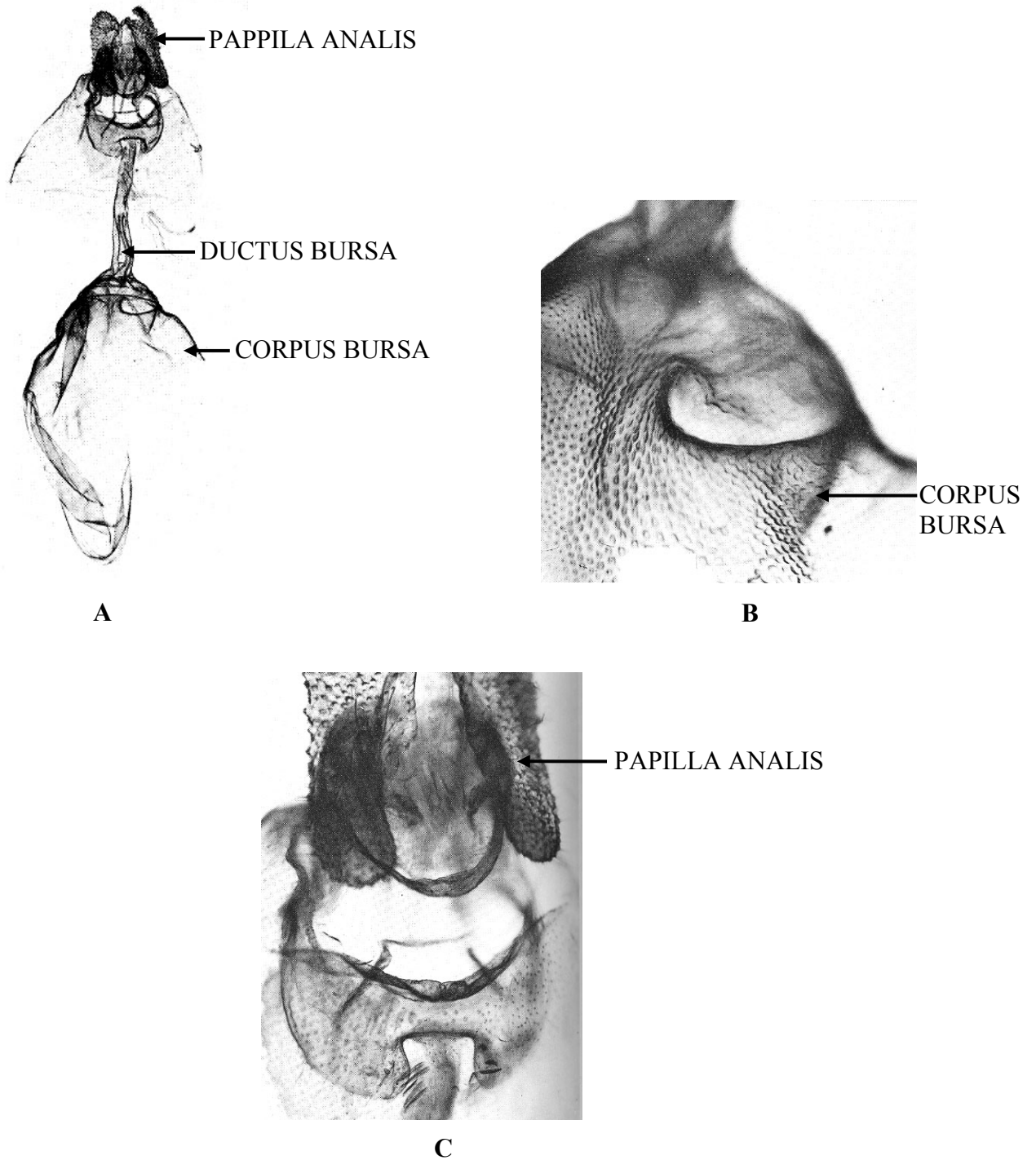


Figure C14. Female genitalia of *Amorbia emigratella* Busck A-entire genitalia, B-detail corpus bursa, C-detail papillae anales and associated structures [Reproduced from Zimmerman (1978)].

Pupa: As in Fig C15. Length 11.5 mm.

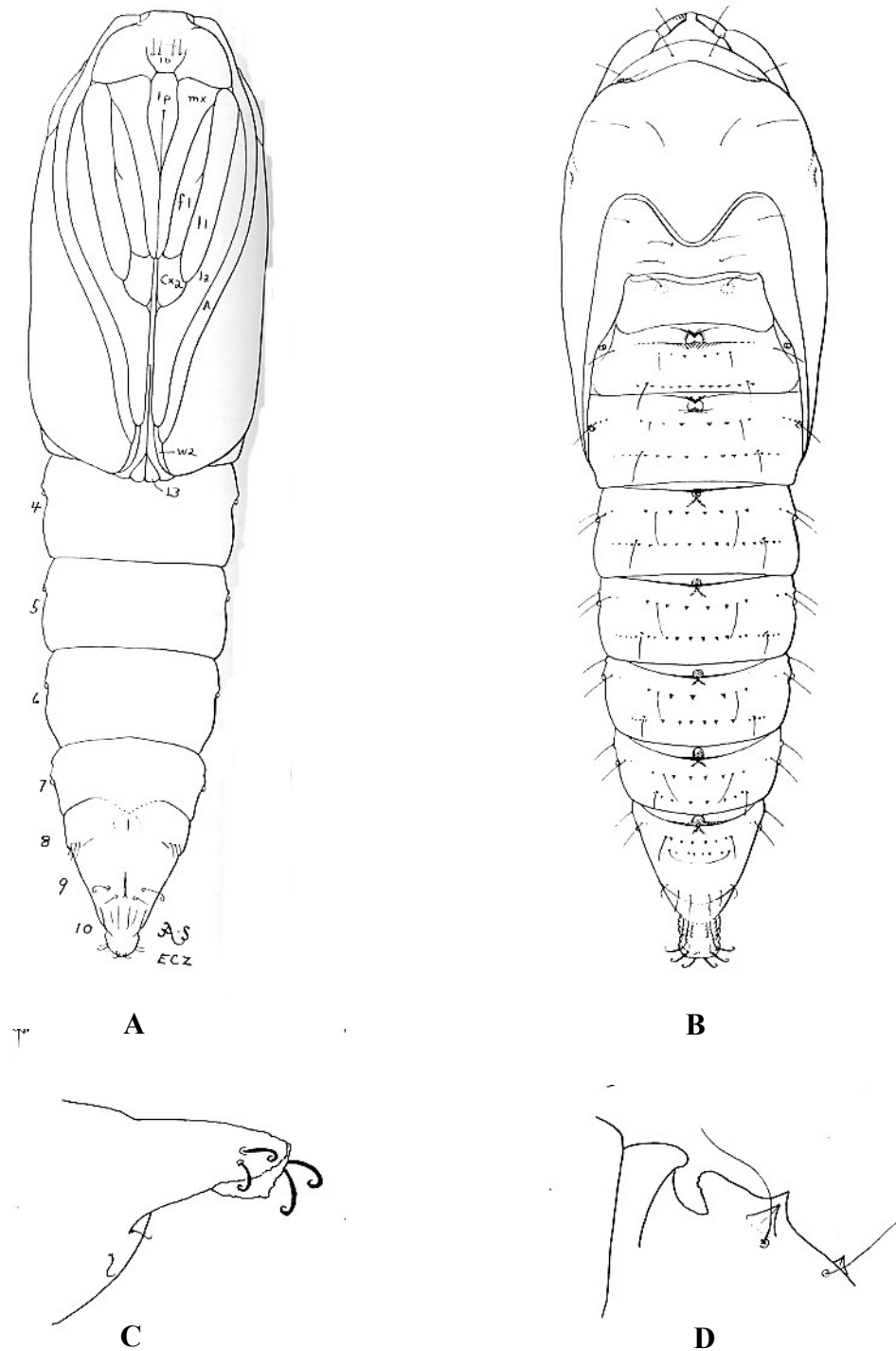


Figure C15. Pupa of *Amorbia emigratella* Busck A-ventral view pupa, B-dorsal view pupa, C-detail lateral view left side cauda of pupa, D-outline left side 8th abdominal tergite. A-antenna; Cx2-mesocoxa; fl-profemora; lb-labrum; lp-labial palpus, 11, 12, 13-legs; mx-galea of maxilla (proboscis), W2-hindwing. Ventral setae mostly omitted.

[Reproduced from Zimmerman (1978)].

Larva: As in Fig C16.

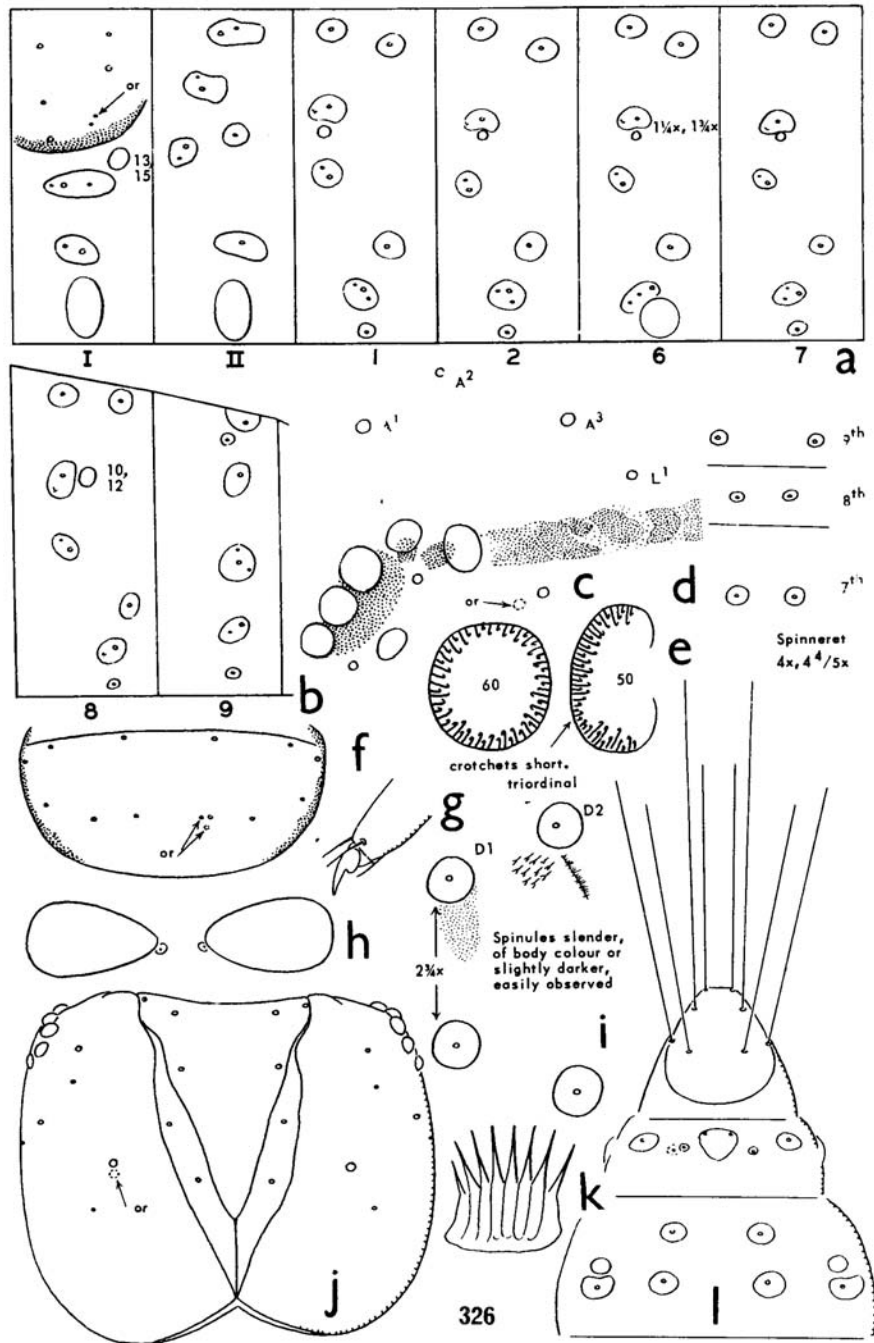


Figure C16. Larva of *Amorbia emigratella* Busck a, setal map of the pro- and mesothorax and abdominal segments, 1,2,6, and 7; b, the same of abdominal segments 8 and 9; c, ocellar area of the left side of the head; d, the VI setae along the midline of the abdominal sternites 7, 8, and 9; e, crochets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