Mini Risk Assessment
Grape berry moth, *Lobesia botrana* (Denis & Schiffermuller)
[Lepidoptera: Tortricidae]

Robert C. Venette, Erica E. Davis, Michelle DaCosta, Holly Heisler, & Margaret Larson
Department of Entomology, University of Minnesota
St. Paul, MN 55108
September 5, 2003

Introduction
Lobesia botrana is a significant pest of berries and berry-like fruits in Europe, the Mediterranean, southern Russia, Japan, the Middle East, Near East, and northern and western Africa (Avidov and Harpaz 1969, CIE 1974). This pest is also known as the European vine moth (Zhang 1994). The likelihood and consequences of establishment by *L. botrana* have been evaluated previously in a pest-specific risk assessment (Fowler and Lakin 2002). The likelihood of *L. botrana* being introduced to the US was considered low, but the consequences of establishment by *L. botrana* were rated high (i.e., severe) (Fowler and Lakin 2002). In a separate evaluation of the pest, the chances of *L. botrana* becoming established in the US were considered high if it should be introduced (USDA 1985).
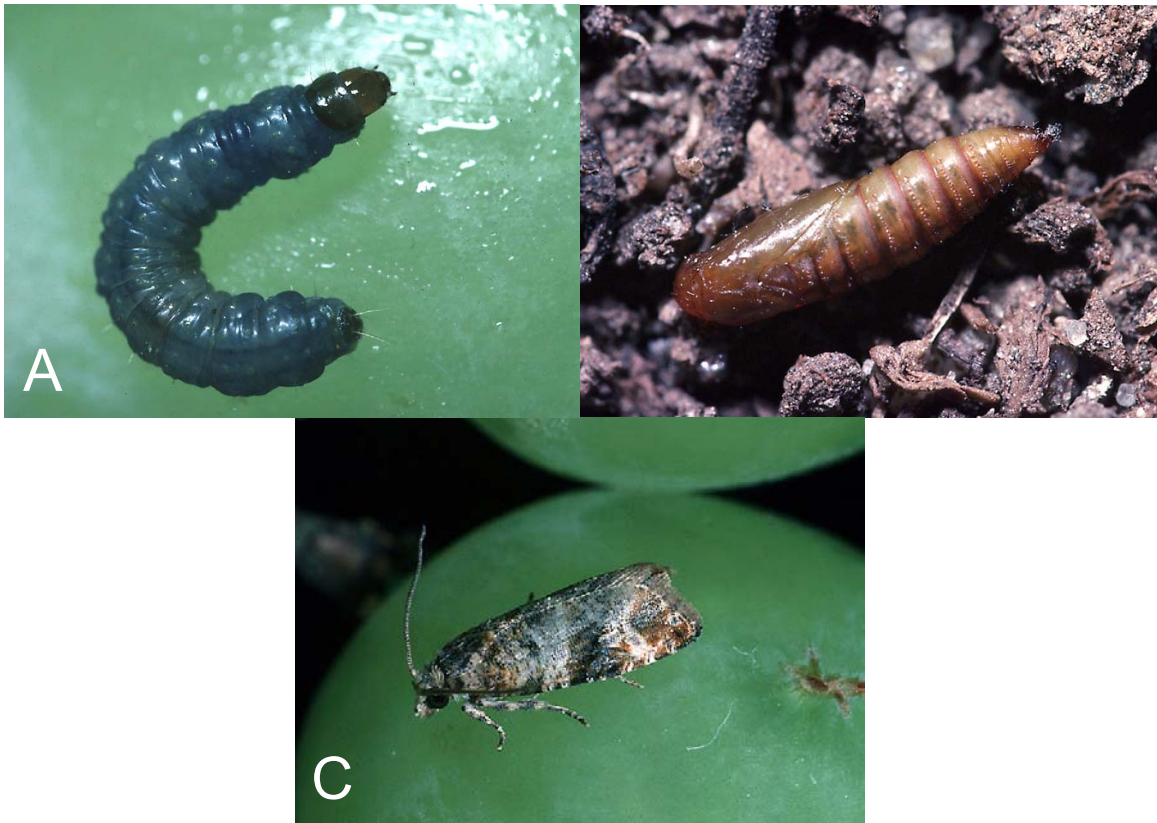

Figure 1. Life stages of *Lobesia botrana*, images not to scale: (A) larva; (B) pupa; and (C) adult. [Photos from Entopix]

1. **Ecological Suitability. Rating: Medium.** *Lobesia botrana* is considered a Palearctic species that has expanded its range into the Ethiopian zoogeographic province (CAB 2003). Climates in the area occupied by this pest can be characterized generally as dry or temperate (CAB 2003). The currently reported global distribution of *L. botrana* suggests that the pest may be most closely associated with biomes classified as montane scrub; Mediterranean scrub; and temperate broadleaf and mixed forests. Based on the type and area of biomes in the US, we estimate that approximately 29% of the continental US may be suitable for *L. botrana* (Fig. 2). This projection includes the major California wine-producing counties of Napa, Sonoma, Amador, Monterey, and San Louis Obispo. See Appendix A for a more complete description of this analysis.
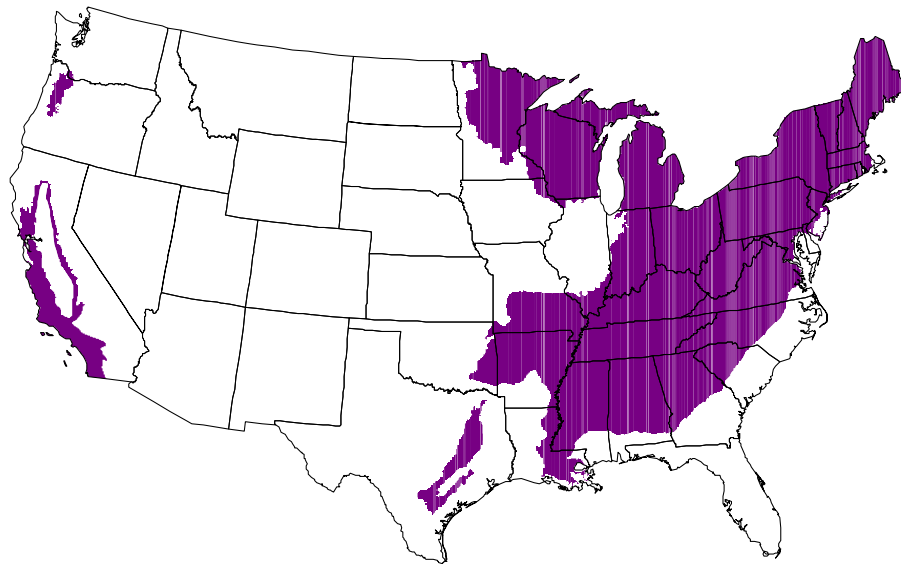

Figure 2. Predicted distribution of *Lobesia botrana* in the continental US.

2. **Host Specificity/Availability. Rating: Medium/Medium.** This pest feeds primarily on the flowers and fruits of grape (*Vitis vinifera*) (Roehrich and Boller 1991, PPQ 1993, CAB 2003). However, *L. botrana* demonstrates the curious behavior of feeding on many different plant families (approx. 27), but only a few species within each family are suitable (Gabel et al. 1992). Some of its hosts belong to Apiaceae, Asteraceae, Compositae, Convolvulaceae, Oleaceae, Polygonaceae, Ranunculaceae, Rhamnaceae, Roseaceae, Thymeleaceae, Umbelliferae and Vitaceae (Savopoulou-Soultani et al. 1990, Stavridis and Savopoulou-Soultani 1998). In addition to grape, other reported host plants include: barberry (*Berberis* spp.), black and red currant (*Ribes nigrum*), blackberry (*Rubus fruticosus*), blackthorn (*Prunus spinosa*), carnation (*Dianthus* spp.), cherry (*Prunus avium*), dogwood (*Swida* spp.), grape (*Vitis vinifera*), gooseberry (*Ribes uva-crispa*), kiwi/Chinese gooseberry (*Actinidia chinensis*), nectarine (*Prunus persica*), persimmon (*Diospyros kaki, D. virginiana*), plum (*Prunus domestica*), pomegranate (*Punica granatum*), and olive (*Olea europaea*

subsp. *europaea*) (Bradley et al. 1979b, USDA 1985, Moleas 1988, PPQ 1993, Zhang 1994, Stavridis and Savopoulou-Soultani 1998, Savopoulou-Soultani et al. 1999, CAB 2003).

Secondary and/or wild hosts include: arbutus (*Arbutus unedo*), blackberry (*Rubus fruticosus*), bloody-twig dogwood (*Cornus sanguinea*), common jujube (*Ziziphus jujuba*), common moonseed (*Menispermum canadense*), cornelian cherry (*Cornus mas*), dewberry (*Rubus caesius*), ivy (*Hedera helix*), lilac (*Syringa vulgaris*), privet (*Ligustrum vulgare*), rosemary (*Rosmarinus officinalis*), spurgeflax daphne (*Daphne gnidium*), Tatarian honeysuckle (*Lonicera tatarica*), travelers joy (*Clematis vitalba*), Virginia creeper (*Parthenocissus quinquefolia*), and the Wayfaring tree (*Viburnum lantana*) (Bradley et al. 1979b, PPQ 1993, Savopoulou-Soultani et al. 1999, CAB 2003). *Lobesia botrana* exhibits an oviposition preference for privet and certain grape cultivars, such as 'Cabernet Sauvignon' (Maher et al. 2000, 2001).

Lobesia botrana females are also attracted to tansy (*Tanacetum vulgare*), specifically to pollen, nectar or damaged plant parts (when flowers are absent); however, no eggs are laid on this plant (Bradley et al. 1979b, Gabel 1992, Stavridis and Savopoulou-Soultani 1998). Larval feeding has also been observed on apples (*Malus domestica*) infected with *Botrytis cinerea* (Savopoulou-Soultani and Tzanakais 1988), though apple is not a well documented primary host.

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

3. **Survey Methodology. Rating: Medium**. Visual inspections of plant materials may be used to detect eggs, larvae, and pupae, of *L. botrana* (USDA 1985). Eggs will frequently be found on flower buds or pedicels (USDA 1985). Larvae will be found in flowers or fruit clusters covered with webbing produced by the insect (USDA 1985). Pupae occur in rolled leaves (USDA 1985). Fruit dissections may be needed to detect larvae (USDA 1985). For field surveys, Badenhausser et al. (1999) recommend a sample unit of a grape vine. Sample units should be selected at random.

A sex pheromone has been identified that is highly attractive to males. Males are most attracted to a five component blend of (*E,Z*)-(7,9)-dodecadienyl acetate, (*E,Z*)-(7,9)-dodecadien-1-ol, (*Z*)-9-dodecenyl acetate, (*E*)-9-dodecenyl acetate, and 11-dodecenyl acetate in a ratio of 10:0.5:0.1:0.1:1 (El-Sayed et al. 1999, 2000). Males are slightly less attracted to a three component blend of (*E,Z*)-(7,9)-dodecadienyl acetate, (*E,Z*)-(7,9)-dodecadien-1-ol, (*Z*)-9-dodecenyl acetate (ratio of 10:0.5:0.1) (El-Sayed et al. 1999, 2000). Males were still attracted, but much less so, to the main pheromone component (*E,Z*)-(7,9)-dodecadienyl acetate (El-Sayed et al. 1999, 2000). The main pheromone component has been used to disrupt mating as a method of pest control (Arn et al. 1988, Bagnoli et al. 1993, Barbieri et al. 1996, Karg and Sauer 1997, Sauer and Karg 1998, Charmillot and

Pasquier 2001) and to monitor the flight period of males (Anshelevich et al. 1994, Al-Zyoud and Elmosa 2001). However, this compound is sensitive to sunlight and degrades, becoming non-attractive to *L. botrana*, after 60 minutes of exposure to UV radiation (Oldenburg et al. 1999).

Pheromone-baited traps (e.g., Pherocon 1C, Zoecon) have been used to monitor male flight activity and to make informed treatment decisions in grape production areas (Anshelevich et al. 1994, Oliva et al. 1996, Al-Zyoud and Elmosa 2001). Traps placed 4 ft high (1.3 m) are generally more effective than traps placed at only 1 ft (0.3 m, Gabel and Renczés 1985). Delta traps catch relatively fewer moths than traps with a more open design, e.g., Traptest traps described as "commercial type (Montedison, Milan, Italy) consisting of two triangular plastic roofs in Havana brown; sticky area 9.89 dm^2 [152 in^2]" (Gabel and Renczés 1982, 1985). When pheromone traps are used, care should be taken to keep foliage away from the entry to the trap (PPQ 1993). Rubber septa used to dispense the pheromone should be replaced every 3 weeks (PPQ 1993, Anshelevich et al. 1994). Traps should be placed approximately 100 ft (30.5 m) apart to avoid inter-trap interference (Anshelevich et al. 1994). Lures for *L. botrana* can be used in the same trap with lures for *Lymantria dispar*, or *Cydia pomonella* (Schwalbe and Mastro 1988).

4. **Taxonomic Recognition**. **Rating: Low.** *Lobesia botrana* may be confused with "the American grape berry moth, *Endopiza viteana*, which occurs in the eastern USA and presents similar bionomics..." (CAB 2003). Another tortricid pest of grape, black currant and plum in Europe, *Eupoecilia ambiguella*, causes similar damage (CAB 2003). Forewings of adult *L. botrana* moths "have a mosaic-shaped pattern with black brown cream, red and blue ornamentation," while forewings of adult *E. ambiguella* are cream colored (CAB 2003). Compared to *E. ambiguella*, "*L. botrana* larvae do not carry any protective silk cover" ...and "*L. botrana* pupation occurs inside a greyish white cocoon that usually does not incorporate vegetal residues and frass" (CAB 2003).

    For a more complete taxonomic and morphological description of *L. botrana*, see Appendix C.

5. **Entry Potential. Rating: Low.** Since 1984, 20 interceptions of *L. botrana* or "*Lobesia* sp." have been reported across the US (USDA 2003). Annually, only 1 (±0.2 standard error of the mean) interception of *L. botrana* or "*Lobesia* sp." has been reported (USDA 2003). These interceptions are largely associated with international airline passengers (95%). One interception reported from mail (5%) was associated with infested figs. The pest has been intercepted only at 7 ports of entry in the US. Most interceptions were reported from JFK International Airport (67%), Port Huron, MI (5%), Chicago (5%), Des Plaines (5%), Detroit (5%), Boston (5%), and San Francisco (5%). These ports are the first points of entry for airline passengers, mail, or cargo coming into the US and do not necessarily

represent the intended final destination of infested material. Movement of potentially infested material is more fully characterized in the next section.

6. **Destination of Infested Material. Rating: Low.** When an actionable pest is intercepted, officers ask for the intended final destination of the conveyance. Material infested with *L. botrana* or "*Lobesia* sp." (either carried by mail or international airline passengers) was destined for five states: New York (67%), Michigan (11%), Illinois (11%), California (5%), and Massachusetts (5%). We note that some portion of each of the states in the continental US has a climate and hosts that would be suitable for establishment by *L. botrana*. We also emphasize that arrivals of *L. botrana* appear to be rare events, based on the number of times it has been intercepted.

7. **Potential Economic Impact. Rating: High.** *Lobesia botrana* is a pest of economic importance in vineyards throughout much of the Palearctic region and portions of the Afrotropical and Oriental regions, causing damage to flowers and developing grapes (Bovey 1966, Ali et al. 1978a, Deseo et al. 1981, USDA 1985, Caffarelli and Vita 1988, Roehrich and Boller 1991, Gabel 1992, Mondy et al. 1997, Fermaud 1998, Moschos et al. 1998, Savopoulou-Soultani et al. 1999, Al-Zyoud and Elmosa 2001, Roditakis and Karandinos 2001, Torres-Villa and Rodríguez-Molina 2002, Amsellem et al. 2003, CAB 2003). Every generation of the moth can be found in vineyards, however the second and third generations are the most damaging. Larvae in latter generations can seriously affect the mature grape berry harvest directly through larval feeding and indirectly by predisposing the crop to grey mold, a fungal infection caused by *Botrytis cinerea* (Deseo et al. 1981, Briere and Pracros 1998, Fermaud 1998, Badenhausser et al. 1999, Savopoulou-Soultani et al. 1999, Mondy and Corio-Costet 2000, Al-Zyoud and Elmosa 2001).

"Damage is greater in grape cultivars with compact clusters and/or sensitive to rot" (Pavan et al. 1993). The following observations, relating to the economic impact of *L. botrana* damage to grapes, were published by Roehrich and Schmid, cited in Roerich and Boller (1991):
- "Damage depends strongly on the developmental stage of the grapevine"
- "Before and during flowering the larvae at first penetrate single flower buds and later on start to tie together several flower buds, building glomerules in which they stay and continue their feeding activities"
- Economic thresholds can vary widely depending on the flower cluster size. For example, "One larva per cluster" is sufficient to cause economic damage in 'Pinot Noir', while "…'Cabernet Sauvignon' can tolerate up to two larvae per flower cluster without reduction of yield"
- Following berry damage and subsequent infection by *Botrytis cinerea*, "The economic thresholds… depend on various aspects, such as whether the grapes are produced as table fruit or for vinification, the level of precipitation (higher or lower risk of *Botrytis* infestation) and the quality and price level of the crop".

8. **Establishment Potential. Rating: Medium.** No infestations of *L. botrana* have been reported in the US. Given the significant area in the US that is likely to provide a suitable climate, establishment is likely if the pest arrives in this area and encounters a suitable host. Previously, surveys were recommended in California, New York, Washington, Michigan, Pennsylvania, Ohio, Arizona, North Carolina and Missouri because of the acreage of grapes grown in these states (PPQ 1993). At the time, the assumption was made that the distribution of hosts would be the only factor to limit establishment. More recent analyses, however, suggest the distribution of the pest may also be limited by climate (Fowler and Lakin 2002). Our analysis concurs with this finding.

For a more detailed description of the biology of *Lobesia botrana*, see Appendix D.

References:

Abashidze, E. 1991. Comparative evaluation of entomophenological prediction methods. Soviet Journal of Ecology 22: 64-69. PDF

Ali, M. A., F. A. Abdel Lateef, A. M. Awadallah, and M. A. Korashy. 1978a. The effect of temperature and humidity on the development of vine grape moth *Lobesia botrana* Schiff., pp. 156-162, Proceedings of the Fourth Conference of Pest Control. Academy of Scientific Research and Technology, Cairo. PDF

Ali, M. A., M. F. A. El-Lateef, A. M. Awadallah, and M. A. Korashy. 1978b. Seasonal abundance and occurrence of *Lobesia botrana* Schiff. larva with special reference to climatic factors effects., pp. 163-168, Proceedings of the Fourth Conference on Pest Control. NRC, Cairo. PDF

Al-Zyoud, F. A., and H. M. Elmosa. 2001. Population dynamics of the grape berry moth, *Lobesia botrana* Schiff. (Lepidoptera: Tortricidae), and its parasites in Jerash Area, Jordan. Dirasat, Agricultural Sciences 28: 6-13. PDF

Amsellem, L., A. M. Risterucci, and B. Benrey. 2003. Isolation and characterization of polymorphic microsatellite loci in *Lobesia botrana* Den. & Schiff. (Lepidoptera: Tortricidae). Molecular Ecology Notes 3: 117-119. PDF

Anshelevich, L., M. Kehat, E. Dunkelblum, and S. Greenberg. 1994. Sex pheromone traps for monitoring the European vine moth, *Lobesia botrana*: Effect of dispenser type, pheromone dose, field aging of dispenser, and type of trap on male captures. Phytoparasitica 22: 281-290. PDF

Arn, H., S. Rauscher, P. Guerin, and H. R. Buser. 1988. Sex pheromone blends of three tortricid pests in European vineyards. Agriculture, Ecosystems and Environment 21: 111-117. PDF

Avidov, Z., and I. Harpaz. 1969. Family Tortricidae: Leaf roller moths. In : Plant Pests of Israel, pp. 380-384. Israel Universities Press, Jerusalem. PDF

Badenhausser, I., P. Lecharpentier, L. Delbac, and P. Pracros. 1999. Contributions of Monte-Carlo test procedures for the study of the spatial distribution of the European vine moth, *Lobesia botrana* (Lepidoptera: Tortricidae) in European vineyards. European Journal of Entomology 96: 375-380. PDF

Bagnoli, B., D. Goggioli, and M. Righini. 1993. Experiments with mating disruption to control the grape moth *Lobesia botrana* (Den. and Schiff.) in the Chianti region. Redia 76: 375-390. PDF

Barbieri, R., G. Cavallini, and A. Pollini. 1996. Grape moths: strategies and experiments in their control. L'Informatore Agrario 52: 75-79. PDF

Bloesch, B., and J. d. Siebenthal. 1988. The air temperature as forecast and warning means for the control of insects. Revue Suisse de Viticulture, Arboriculture, Horticulture 20: 121-126. PDF

Bovey, P. 1966. Superfamille des Tortricidae--L'Eudemis de la vigne. Entomologie appliquee a l'agriculture 2: 859-887. PDF

Bradley, J. D., W. G. Tremewan, and A. Smith. 1979a. *Cydia funebrana* (Treitschke), pp. 248-250, British Tortricioid Moths - Tortricidae: Olethreutinae. The Ray Society, London.

Bradley, J. D., W. G. Tremewan, and A. Smith. 1979b. *Lobesia botrana* (Denis & Schiffermüller), pp. 69-70, British Tortricoid Moths - Tortricidae: Olethreutinae. The Ray Society, London, England. PDF

Bradley, J. D., W. G. Tremewan, and A. Smith. 1979c. List of British species of Tortricidae: Olethreutinae, London.

Briere, J., and P. Pracros. 1998. Comparison of temperature-dependent growth models with the developemnt of *Lobesia botrana* (Lepidoptera: Tortricidae). Environmental Entomology 27: 94-101. PDF

CAB. 2003. Crop protection compendium: global module. Commonwealth Agricultural Bureau International, Wallingford, UK.

Caffarelli, V., and G. Vita. 1988. Heat accumulation for timing grapevine moth control measures. Bulletin SROP 11: 24-26. PDF

Castro, A. R. 1943. Fauna entomologica de la vid en España. Estudio sistematico-biologico de las especies de mayor importanica económica. Instituto español de entomologia, Madrid. PDF

Charmillot, P. J., and D. Pasquier. 2001. Mating disruption, classical control and population dynamic of grape moths. Bulletin OILB-SROP 24: 87-90. PDF

CIE. 1974. *Lobesia botrana* (Schiff.). Distribution Maps of Pests, Series A, Map No. 70 (revised). Commonwealth Institute of Entomology/Commonwealth Agricultural Bureau, Wallingford, UK. PDF

Coscolla, R., J. Sanchez, and V. Beltran. 1986. Preliminary study on the mortality of eggs of *Lobesia botrana* Den. & Schiff. caused by high temperatures and low relative humidities in the laboratory. Boletin de Sanidad Vegetal, Plagas 12: 3-7. PDF

CSIRO. 1991. Insects of Australia: a textbook for students and research workers. Cornell University Press, Ithaca, New York.

Deseo, K. V., F. Marani, A. Brunelli, and A. Bertaccini. 1981. Observations on the biology and diseases of *Lobesia botrana* Den. and Schiff. (Lepidoptera, Tortricidae) in central-north Italy. Acta Phytopathologica Academiae Scientiarum Hungaricae 16: 405-431. PDF

Eghtedar, E. 1996. Biology of *Lobesia botrana* in Fars province. Applied Entomology and Phytopathology 63: 5-6. PDF

El-Sayed, A., J. Gödde, and A. Heinrich. 2000. A computer-controlled video system for real-time recording of insect flight in three dimensions. Journal of Insect Behaviour 13: 881-900. PDF

El-Sayed, A., J. Gödde, P. Witzgall, and A. Heinrich. 1999. Characterization of pheromone blend for grapevine moth, *Lobesia botrana* by using flight track recording. Journal of Chemical Ecology 25: 389-400. PDF

Fermaud, M. 1998. Cultivar susceptibility of grape berry culsters to larvae of *Lobesia botrana* (Lepidoptera: Tortricidae). Journal of Economic Entomology 91: 974-980. PDF

Filip, I. 1983. Determination of the thermal constants of the development necessary to the ecological substantiation of the integrated control of *Lobesia botrana* Den. et Schiff. Probleme de Protecotia Plantelor. 11: 11-18. PDF

Fowler, G., and K. Lakin. 2002. Risk Assessment: Vine Moth, *Lobesia botrana* (Denis and Schiffermuller), (Lepidoptera: Tortricidae), pp. 1-17. USDA-APHIS, Center for Plant Health Science and Technology (Internal Report), Raleigh, NC. PDF

Gabel, B. 1981. Effects of temperature on the devevlopemnt and reproduction of the grape moth *Lobesia botrana* Den. et Schiff. (Lepid., Tortricidae). Anzeiger für Schadlingskunde Pflanzenschutz Umweltschutz 54: 83-87. PDF

Gabel, B. 1992. Tansy flowers attract European grapevine moth females, *Lobesia botrana* Den. & Schiff. (Lep., Tortricidae). Journal of Applied Entomology/Zeitschrift für Angewandte Entomologie 113: 153-158. PDF

Gabel, B., and V. Renczés. 1982. Effects of design and siting of pheromone traps in monitoring the grape vine moth, *Lobesia botrana* (Lepidoptera, Tortricidae). Acta Entomologica Bohemoslovaca 79: 260-266. PDF

Gabel, B., and V. Mocko. 1984a. Forecasting the cyclical timing of the grape vine moth, *Lobesia botrana* (Lepidoptera, Tortricidae). Acta Entomologica Bohemoslovaca 81: 1-14. PDF

Gabel, B., and V. Renczés. 1985. Factors affecting the monitoring of flight activity of *Lobesia botrana* and *Eupoecilia ambiguella* (Lepidoptera, Tortricidae) by pheromone traps. Acta Entomologica Bohemoslovaca 82: 269-277. PDF

Gabel, B., and D. Thiéry. 1994a. Non-host plant odor (*Tanacetum vulgare*: Asteracea) affects the reproductive behavior of *Lobesia botrana* Den. et Schiff (Lepidoperta: Tortricidae). Journal of Insect Behaviour 7: 149-157. PDF

Gabel, B., and D. Thiéry. 1994b. Semiochemicals from *Lobesia botrana* (Lepidoptera: Tortricidae) eggs deter oviposition by the codling moth *Cydia pomonella* (Lepidoptera: Tortricidae). European Journal of Entomology 91: 353-359. PDF

Gabel, B., and R. Roehrich. 1995. Sensitivity of grapevine phenological stages to larvae of European grapevine moth, *Lobesia botrana* Den. et Schiff. (Lep., Tortricidae). Journal of Applied Entomology 119: 127-130. PDF

Gabel, B., D. Thiéry, V. Suchy, F. Marion-Poll, P. Hradsky, and P. Farkas. 1992. Floral volatiles of *Tanacetum vulgare* L. attractive to *Lobesia botrana* Den. et Schiff. females. Journal of Chemical Ecology 18: 693-701. PDF

Gabel, V., and V. Mocko. 1984b. Temporal analysis of the fertilization in the field population of the grape vine moth, *Lobesia botrana* Den. and Schiff. (Lep., Tortricidae). Zeitschrift für Angewandte Entomologie 98: 380-389. PDF

Genduso, P. 1985. Observations on *Lobesia botrana* (Den. & Schiff.) and *Eupoecilia ambiguella* (Hb.) in Sicily, pp. 409-410, Congresso Nazionale Italiano di Entomologia. Tipografia compositori, Palermo, Erice, Bagheria. PDF

Hannemann, H. 1961. Tribus: Olethreutini Obraztsov, pp. 180-220, Die Tierwelt Deutschlands und der Angrenzenden Meeresteile. Veb Gustav Fischer Verlag. PDF

Heinrich, C. 1926. Revision of the North American moths of the subfamilies Laspeyresiinae and Olethreutinae. Smithsonian Institution, United States National Museum, Washington. PDF

Karg, G., and A. Sauer. 1997. Seasonal variation of pheromone concentration in mating disruption trials against European grape vine moth *Lobesia botrana* (Lepidoptera: Tortricidae) measured by EAG. Journal of Chemical Ecology 23: 487-501. 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.

Maher, N. M., M. E. Toulouse, J. Jolivet, and D. Thiéry. 2000. Oviposition preference of the European grapevine moth, *Lobesia botrana* (Lepidoptera: Tortricidae) for host and non-host plants present in Bourdeaux area. Bulletin OILB-SROP 23: 131-134. PDF

Maher, N. M., J. Jolivet, D. Thiéry, and C. Lozzia. 2001. Preference on the European grapevine moth, *Lobesia botrana* (Lepidoptera, Tortricidae) between different types of vine: influence of chemical information on the surface of berries. Bulletin OILB-SROP 24: 103-107. PDF

Moleas, T. 1988. *Lobesia botrana* Den. et Schiff. (Tortricidae - Lepidoptera), a potential danger for kiwi (*Actinidae chinensis* Planchon). Informatore Fitopatologico 12: 71-73. PDF

Mondy, N., and M. Corio-Costet. 2000. The response of the grape berry moth (*Lobesia botrana*) to a dietary phytopathogenic fungus (*Botrytis cinerea*): the significance of fungus sterols. Journal of Insect Physiology 46: 1557-1564. PDF

Mondy, N., C. Caïssa, N. Pitoizet, and J. Delbecque. 1997. Effects of the ingestion of *Serratula tinctoria* extracts, a plant containing phytoecdysteroids, on the develoment of the vineyard pest *Lobesia botrana* (Lepidoptera: Tortricidae). Archives of Insect Biochemistry and Physiology 35: 227-235. PDF

Moschos, T., T. Broumas, C. Souliotis, A. Tsourgianni, and V. Kapothanassi. 1998. Experiments on the control of the European grapevine moth *Lobesia botrana* Den. et Schiff. (Lepidoptera, Tortricidae) with the mating disruption method in the area of Spata Attiki, Greece. Anales de l'Institut Phytopathologique Benaki 18: 81-95. PDF

Oldenburg, C., I. Oprean, B. Klima, and H. Hummel. 1999. Degradation of synthetic pheromones by environmental factors. Mededelingen Faculteit Landbouwkundige en Toegepaste Biologische Wetenschappen Universiteit Gent. 64: 89-100. PDF

Oliva, J., G. Navarro, A. Barba, M. Cámara, and S. Navarro-García. 1996. Integrated pest control on vineyard. Mededelingen Faculteit Landbouwkundige en Toegepaste Biologische Wetenschappen Universiteit Gent. 61: 589-596. 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.

Pavan, F., V. Girolami, A. Cecchini, and E. Turbian. 1993. Evolution of damage of grape berry moths, *Lobesia botrana* (Den. & Schiff.) and *Eupoecilia ambiguella* (Hb.), in north-eastern Italy and chemical control. Redia 76: 417-431. PDF

PPQ. 1993. Fact sheet for exotic pest detection survey recommendations. Cooperative Agricultural Pest Survey (CAPS) and Plant Protection and Quarantine, US Department of Agriculture. http://www.ceris.purdue.edu/napis/pests/misc/fexotic.txt.

Rapagnani, M. R., V. Caffarelli, and M. Barlattani. 1989. Ovideposizione a diverse temperature costanti e variabili di *Lobesia botrana* Den. et Schiff. (Lepidoptera - Tortricidae). Bollettino del Laboratorio di Entomologia Agraria di Portici 46: 45-57. PDF

Razowski, J. 1989. The genera of Tortricidae (Lepidoptera). Part II: Palaearctic Olethreutinae. Acta Zoological Cracoviensia 32: 107-328. PDF

Roditakis, N., and M. Karandinos. 2001. Effects of photoperiod and temperature on pupal diapause induction of grape berry moth *Lobesia botrana*. Physiological Entomology 26: 329-340. PDF

Roehrich, R., and E. Boller. 1991. Tortricids in vineyards., pp. 507-514. *In* L. P. S. Van der Geest and H. H. Evenhuis [eds.], Tortricid Pests: Their Biology, Natural Enemies and Control. Elsevier, Amsterdam. PDF

Sauer, A., and G. Karg. 1998. Variables affecting pheromone concentration in vineyards treated for mating disruption of grape vine moth, *Lobesia botrana*. Journal of Chemical Ecology 24: 289-302. PDF

Savopoulou-Soultani, M., and M. Tzanakais. 1988. Development of *Lobesia botrana* (Lepidoptera: Tortricidae) on grapes and apples infected with the fungus *Botrytis cinerea*. Environmental Entomology 17: 1-6. PDF

Savopoulou-Soultani, M., D. G. Stavridis, and M. E. Tzanakakis. 1990. Development and reproduction on *Lobesia botrana* on vine and olive inflorescences. Entomologia Hellenica: 29-35. PDF

Savopoulou-Soultani, M., N. Nikolaou, and P. Milonas. 1999. Influence of maturity stage of grape berries on the development of *Lobesia botrana* (Lepidoptera: Tortricidae) larvae. Ecology and Behaviour 92: 551-556. PDF

Schwalbe, C., and V. Mastro. 1988. Multispecific trapping techniques for exotic-pest detection. Agriculture, Ecosystems and Environment 21: 43-51.

Stavridis, D. G., and M. Savopoulou-Soultani. 1998. Larval performance on and oviposition preference for known and potential hosts by *Lobesia botrana* (Lepidoptera: Tortricidae). European Journal of Entomology 95: 55-63. PDF

Torres-Vila, L. M., J. Stockel, and M. C. Rodriguez-Molina. 1996. Effects of the unavailability of water on the biotic potential of the European grapevine moth Lobesia botrana Den. y Schiff. (Lepidoptera: Tortricidae). Boletin de Sanidad Vegetal, Plagas 22: 443-449. PDF

Torres-Vila, L. M., J. Stockel, P. Lecharpentier, and M. C. Rodríguez-Molina. 1997. Artificial selection in pheromone permeated air increases mating ability of the European grape vine moth *Lobesia botrana* (Lep., Tortricidae). Journal of Applied Entomology 121: 189-194. PDF

Torres-Villa, L., and M. Rodríguez-Molina. 2002. Egg size variation and its relationship with larval performance in the Lepidoptera: the case of the European grapevine moth *Lobesia botrana*. Oikos 99: 272-283. PDF

Torres-Villa, L., J. Stockel, and R. Roehrich. 1995. Le potentiel reproducteur et ses variables biotiques associées chez le mâle de l'Eudémis de la vigne *Lobesia botrana*. Entomologia Experimentalis et Applicata 77: 105-119. PDF

Torres-Villa, L., J. Stockel, and M. Rodríguez-Molina. 1997. Physiological factors regulating polyandry in *Lobesia botrana* (Lepidoptera: Tortricidae). Physiological Entomology 22: 387-393. PDF

Torres-Villa, L., M. Rodríguez-Molina, and J. Stockel. 2002a. Delayed mating reduces reproductive output of female European grapveine moth, *Lobesia botrana* (Lepidoptera: Tortricidae). Bulletin of Entomological Research 92: 241-249. PDF

Torres-Villa, L., J. Gragera, M. Rodríguez-Molina, and J. Stockel. 2002b. Heritable variation for female remating in *Lobesia botrana*, a usually monandrous moth. Animal Behaviour 64: 899-907. PDF

USDA. 1985. Pests not known to occur in the United States or of limited distribution, No. 60: European grape vine moth, pp. 1-10. 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.

Velimirovic, V. 1975. A supplement to the study of *Lobesia* (Polychrosis) *botrana* Den. & Schiff. of ashen vine moth. Zastita Bilja 26: 85-91. PDF

Zeki, C. 1996. Organization and operation of forecasting and warning systems against pests in Turkey. Bulletin OEPP 26: 587-593. PDF

Zhang, B. C. 1994. Index of economically important Lepidoptera. CAB International, Wallingford, UK.

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.
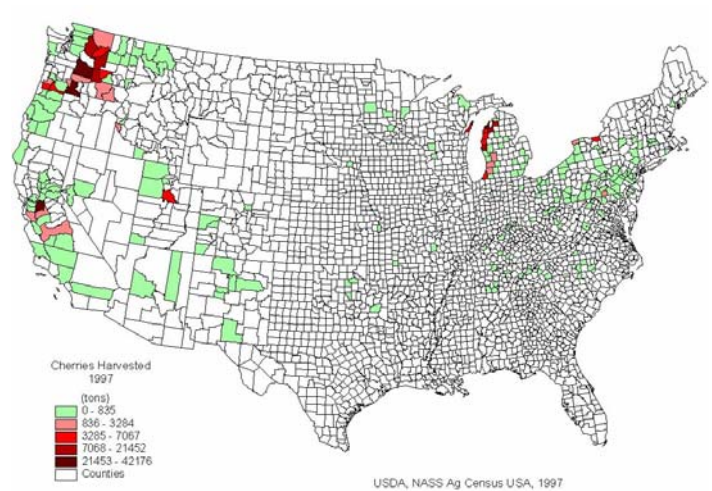
Appendix B. Commercial production of hosts of *Lobesia botrana* in the continental US.
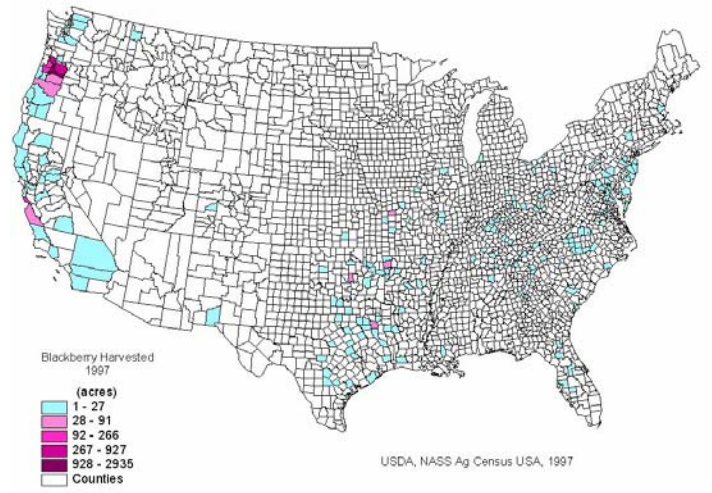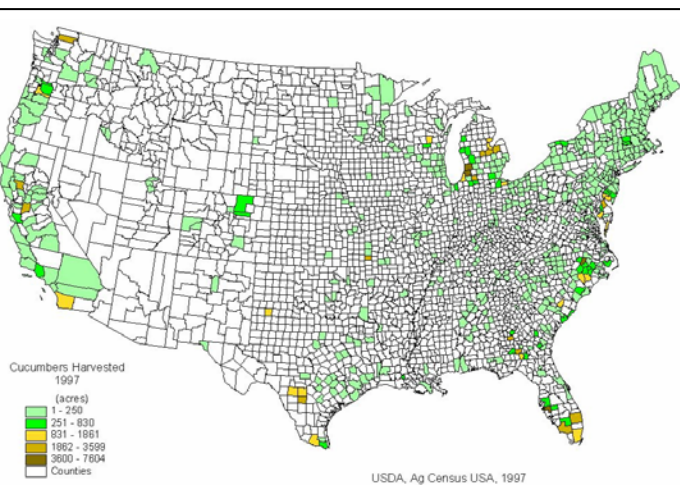
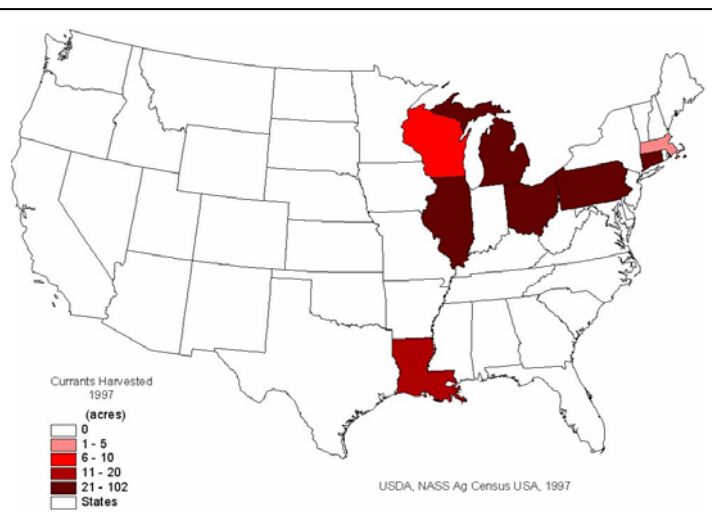Crop Map 1. Blackberry (*Rubus fruticosus*)
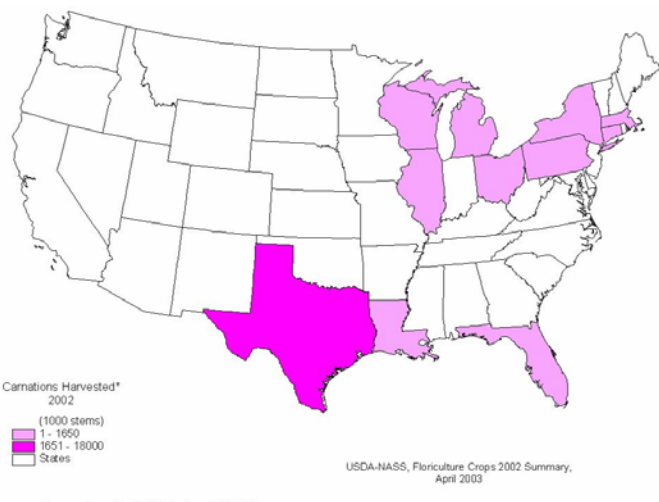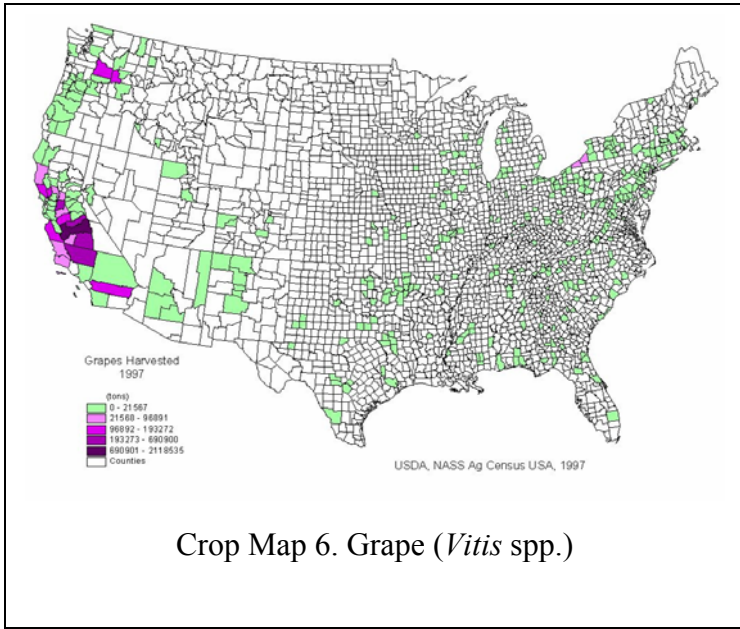
Crop Map 2. Carnation (*Dianthus* spp.)
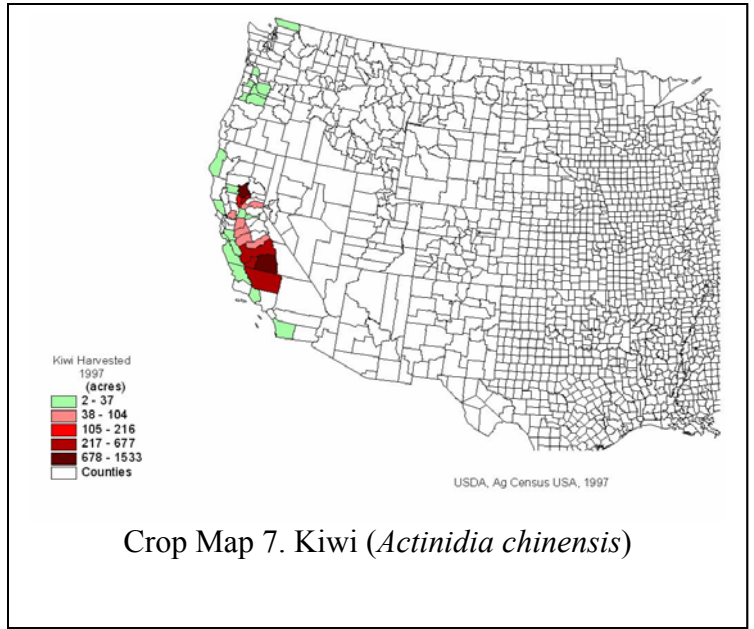
Crop Map 3. Cherry (*Prunus avium*)
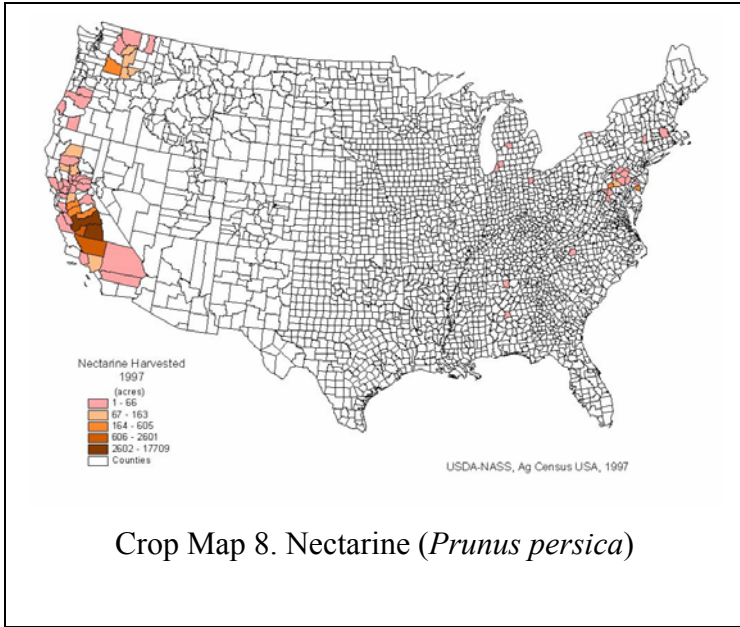
Crop Map 4. Cucumber (*Cucumis sativus*)
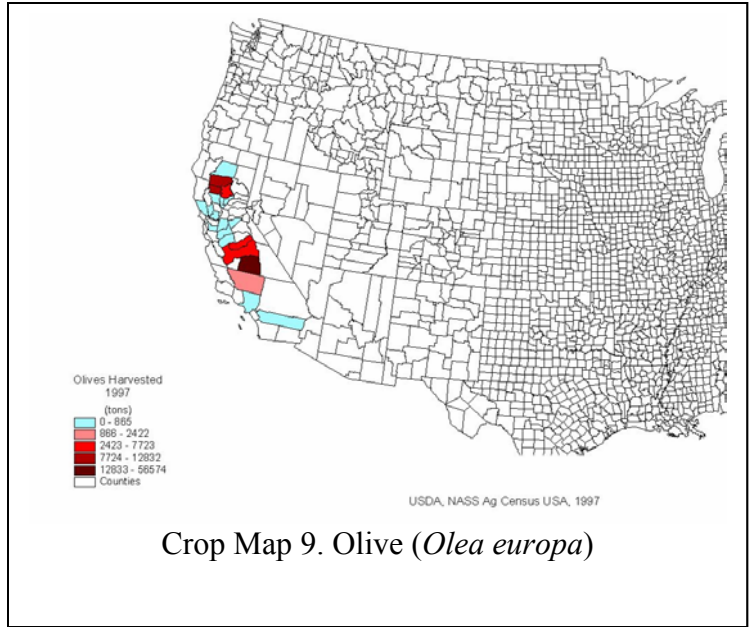
Crop Map 5. Currant (*Ribes rubrum*)
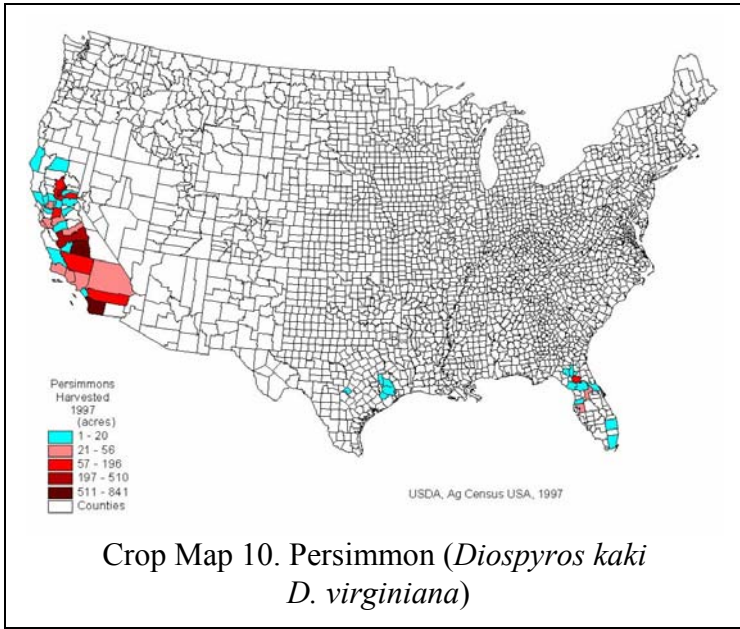
Crop Map 6. Grape (*Vitis* spp.)
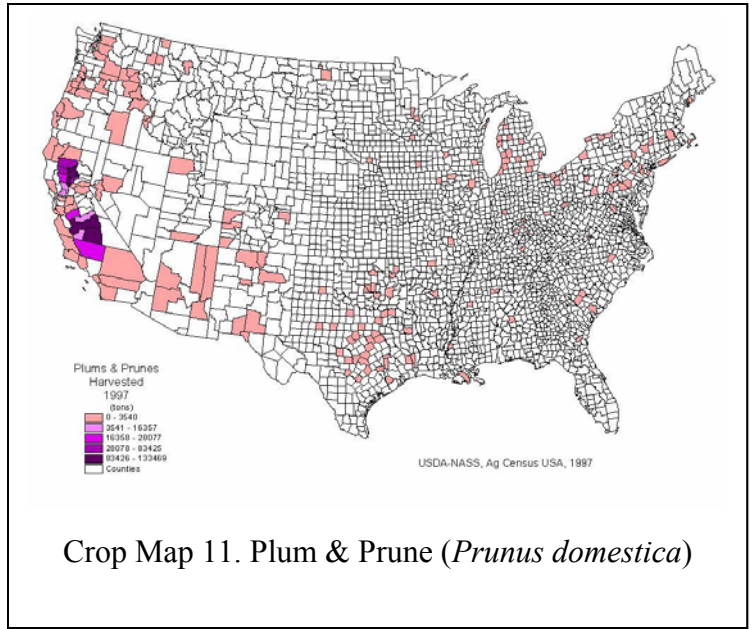

Crop Map 7. Kiwi (*Actinidia chinensis*)

Crop Map 8. Nectarine (*Prunus persica*)
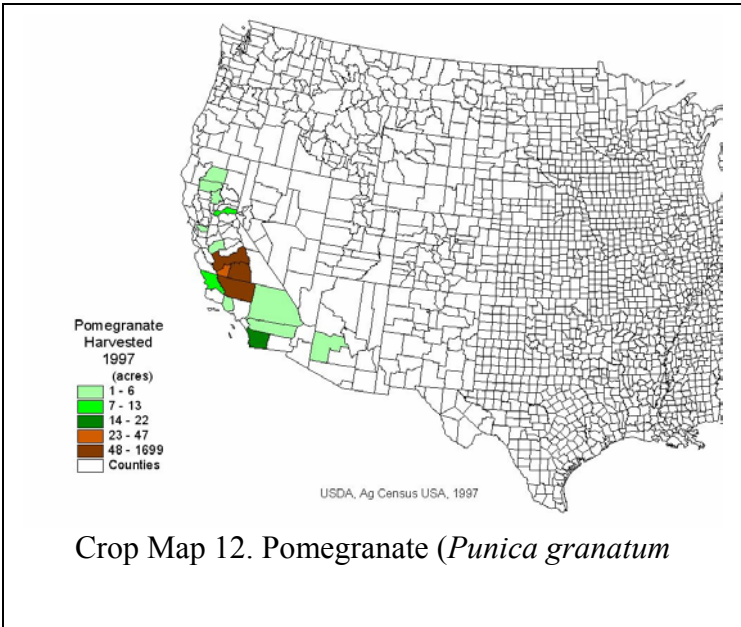

Crop Map 9. Olive (*Olea europa*)

Crop Map 10. Persimmon (*Diospyros kaki D. virginiana*)

Crop Map 11. Plum & Prune (*Prunus domestica*)

Crop Map 12. Pomegranate (*Punica granatum*

Appendix C. Taxonomy of *Lobesia botrana* (Denis & Schiffermüller) and related Tortricidae (prepared by M. DaCosta)
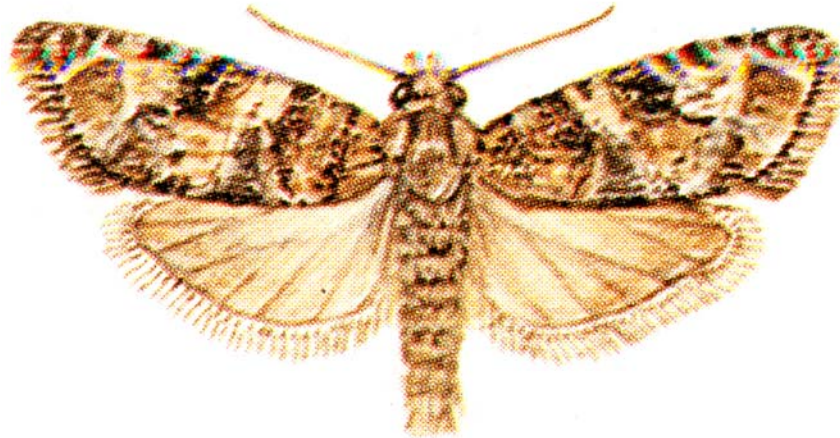

Figure C1. *Lobesia botrana*-male [Image reproduced from Bradely et al. (1979c)]

<u>**Synonyms**</u> (provided by John Brown, National Museum of Natural History, personal communication)

At the generic level:
Lobesia Guenée, 1845, Annales de la. Société Entomologique de France Part 2, (3): 297. Type species: *Asthenia reliquana* Hübner, 1825.

- *Polychrosis* Ragonot, 1894, Ann. Soc. Entomol. Fr. 63: 209. Type species: *Tortrix botrana* (Denis & Schiffermüller), 1775.
- *Lomaschiza* Lower, 1901, Trans. Roy. Soc. South Austral. 25: 68. Type species : *Lomaschiza physophora* Lower 1901.
- *Byrsoptera* Lower, 1901. Trans. Royal Soc. South Austral. 25: 77. Type species *Byrsoptera xylistis* Lower, 1901. (preoccupied).
- *Steriphotis* Meyrick, 1911, Proc. Linnean Soc. N. S. Wales 36: 259. Type species *Steriphotis peltophora* Meyrick, 1911.
- *Analdes* Turner, 1916, Trans. Roy. Soc. South Austral. 40: 533. Type species *Analdes hypolepta* Turner, 1916.
- *Lomaschizodes* Diakonoff, 1954, Zool. Verh. (Leiden) 22: 15. Type species: *Grapholitha extrusana* Walker, 1863.
- *Steriophatis* Bradley, 1961, Bull. Brit. Mus. (Nat. Hist.) Entomol. 10: 00. (Misspelling *Steriphotis*).
- *Harmosma* Diakonoff, 1963, Tidjscher. Entomol. 106: 354. Type species: *Polychrosis harmonia* Meyrick, 1908.
- *Neolobesia* Bae & Komai, 1991, Tyo Ga 42: 136. Type species: *Lobesia coccophagus* Falkovitsh, 1970. (subgenus *Lobesia*).
- *Pirireisia* Kocak, 1981, Priamus 1: 114. (replacement name).

- *Neodasyphora* Bae & Liu, 1995, Japan J. Entomol. 63: 108. Type species: *Polychrosis cunninghamiacola* Liu & Bai, 1977. (subgenus of *Lobesia*)

At the species level:
botrana (Denis & Schiffermüller), 1776 (Tortrix), Syst. Verz. Schmett. Wien. Gegend.: 131. TL: Austria (Vienna). HT: Unknown.
- *vitisana* Jacquin, 1789 (Phalaena), Collectanea 2: 97. TL: Austria. HT: Unknown
- *rosmariana* Millière, 1866 (Olindia, Ann. Soc. Linn. Lyon 13 (1865): 8. TL: France. HT: MNHN
- *flavosquamella* Dufrane, 1960 (*Polychrosis botrana* form), Bull. Inst. Sci. Nat. Belg. 36 (29): 7. TL: France. HT: Unknown.

Diagnosis of *Lobesia botrana*
[Description from Hannemann (1961). Translated by John Luhman, Minnesota Department of Agriculture & Department of Entomology, University of Minnesota.]

Male clasper lacks spine at base.

Description
***Head*:** [Description from Hannemann (Hannemann 1961). Translated by J. Luhman]

Male antenna with short, sparse hairs. Labial palps extended just after the front. Middle segment widened distally, apical segment more or less curved.

***Male Wings*:** See Figure C1. Figure C2 describes variation that may be encountered in wing patterns and provides explanation of morphological terminology.
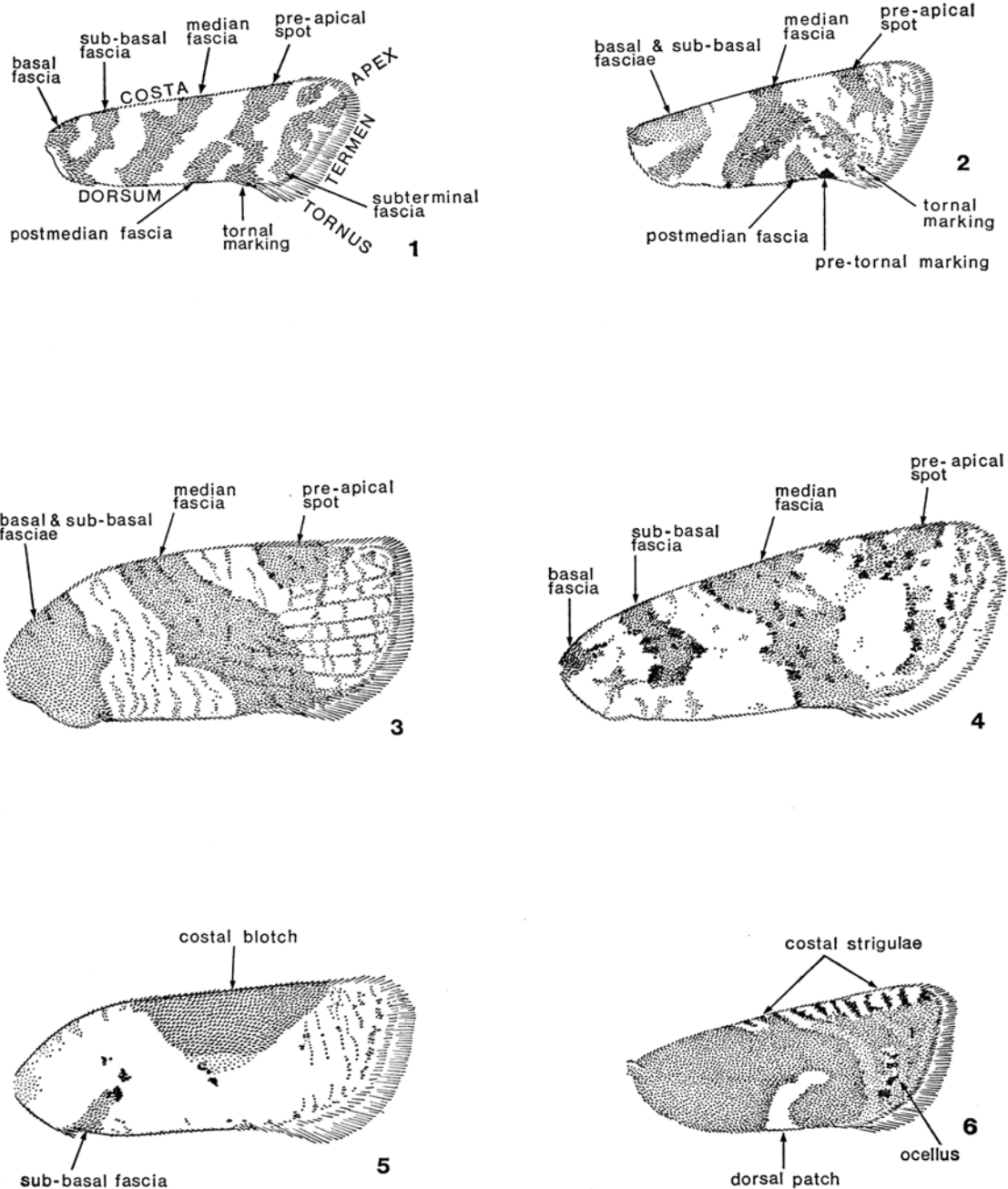
Figure C2. Variation in wing patterns of Tortricoid moths
[Reproduced from Bradely et al. (1979c)].

[Description from Bradley et al. (1979a)] Forewing ground color cream-white. Weakly overlaid with a yellowish color and heavily suffused with bluish-gray between sub-basal and median fasciae medio-dorsally and in costal and dorsal areas beyond median fascia, costa obscurely strigulate with black; fasciate markings moderately well defined but diffuse, yellowish color suffused with light olive-brown, with an admixture of black; basal and sub-basal fasciae usually coalescent and forming a basal patch, its outer edge shallowly convex and irregular; median fascia narrow on costa and dorsum, produced

distad at middle, with a strong admixture of black in outer margin from costa to near middle which sometimes forms a patch above the medial projection; pre-tornal marking obsolete or indicated by a small dark brown spot; tornal marking moderately well developed and usually distinct, subtriangular; subterminal fascia arising from middle of termen and forming a large quadrate patch in upper part of distal area; cilia cream-white, apices suffused with yellowish color, with a gray sub-basal line. Hindwing white, weakly scaled and translucent basally, infuscate distally, most strongly in apical area; cilia white, apices suffused with gray, with a dark gray sub-basal line. Wing spread 5-7mm.

Female Wings: Forewing coloration and markings similar to those of male, but hindwing entirely dark grayish fuscous.

Variation: Considerable minor variation occurs, especially in the strength of the black admixture and the clarity of the fasciate markings of the forewing, see Figure C2.

Venation: [Description from Razowski (1989)]. In males long pterostigma [pigmented spot or cell on anterior margin of wing, usually near or just behind the apex of vein R1 (Torrie Bueno Glossary of Entomology)] extending from end of Sc as far as to r4 developed, chorda from mid-distance between r1-r2, to base of r5, r4-r5 strongly approximate basally or extending from one point, M atrophying posteriorly; in hindwing rr-m1 originating in one point, m3-cu1 short stalked (Figure C3).
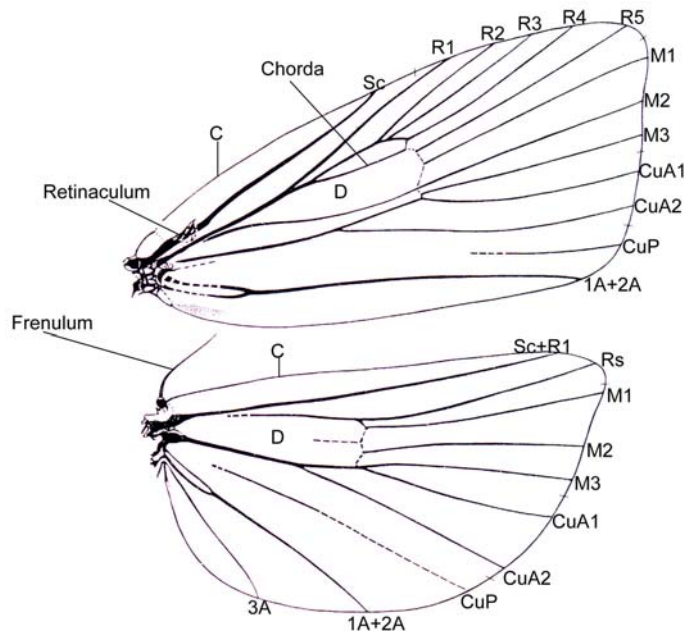

Figure C3. Wing venation of Tortricidae [Reproduced from CSIRO (1991)] A-anal; C-Costa, Cu-Cubitus (CuA1-1st anterior cubitus; CuA2-2nd anterior cubitus; CuP-posterior cubitus); D-discal cell; M-Media, R-Radius, Sc-Subcosta.

Scent organs: Posterior tibia with short bunch of scales; lateral pockets in abdomen developed.

Ovum: Lenticular [i.e., resembling a lentil in shape], at first yellowish but later becoming opalescent gray. Deposited on fruit and stems of the food plant.

Larva: [Description from Bradley et al. (1979a)] Head yellowish brown, longer than wide; prothoracic plate brown, sometimes darker on margin; abdomen varying from yellowish green to whitish brown or brown, integument finely shagreened; thoracic legs brown, anal plate light brownish yellow; anal comb present, with 6-8 prongs. See Figure C4.

[Description from Castro (1943). Translated by Mario Carillo-Vilchez, Department of Entomology, University of Minnesota.] Body parallel sided, thinner anteriorly and posteriorly; 9-10mm long and 1.7mm wide at maximum development. Body may be transulcent and gut visible in which case body color is color of gut. Cuticle "bumpy", each bump ending in a short delicate spine of darker color. Antennae short and retracted almost completely in a depression.

ANTERIOR

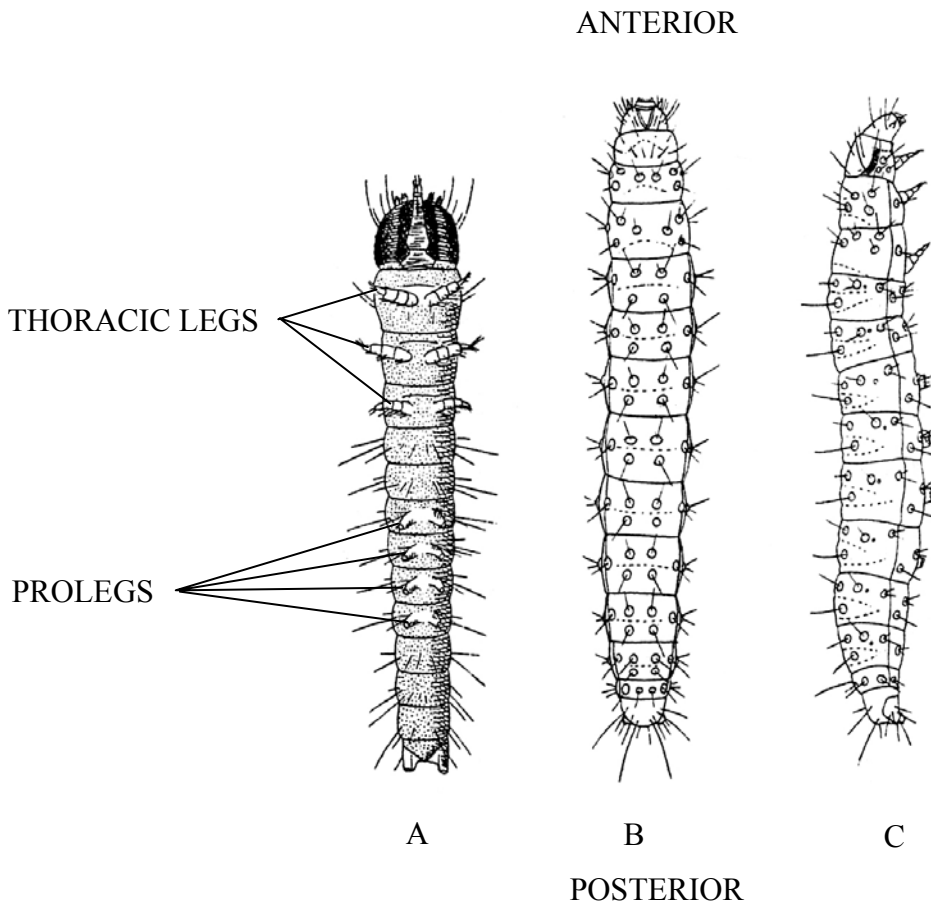THORACIC LEGS

PROLEGS

A B C

POSTERIOR

Figure C4. A. Ventral view of neonate larva, B. Dorsal view last instar larva, C. Lateral view last instar larva. [Reproduced from Castro (1943). Translated by Mario Carillo-Vilchez, Department of Entomology, University of Minnesota].

Pupa: [Description from Castro (1943). Translated by Mario Carillo-Vilchez, Department of Entomology, University of Minnesota.] Large, thin oval with rounded anterior; 5-6mm long x 1.6-1.7mm wide; Uniform green color, darker dorsally; cuticle with some microscopic, pointy bumps; dorsal region of abdominal segments from 2nd to 10th with small spines on the central part; all pupae covered with gray dust. See Figure C5.

ANTERIOR
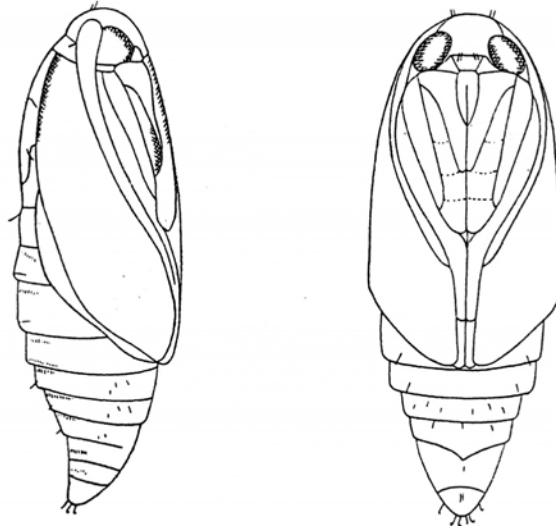
A   B

C   D

POSTERIOR

Figure C5. A. Lateral view, B. Ventral view of pupa. C. Detail dorsal view, posterior of pupa, D. Detail ventral view, posterior of pupa [Reproduced from Castro (1943). Translated by Mario Carillo-Vilchez, Dept. of Entomology, University of Minnesota].
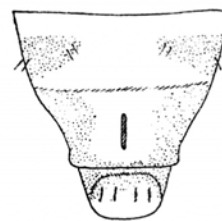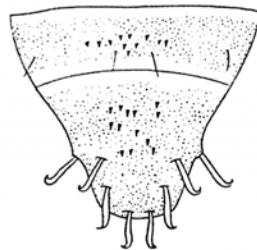
Male genitalia: [Description from Razowski (1989)]. Terminology follows Klots (1970).
Tegumen tapering terminally; pedunculus slender with apodeme m4 strongly elongate,
thin apically; uncus almost completely atrophied, socius occasionally preserved, bristled,
tuba analis usually membranous, simple. Sacculus with groups of spines variably
separated from one another, usually represented by a median agglomeration; cucullus
with one, sometimes atrophying very long spine situated dorso-anteriorly to its ventral
angle; fold vestigial or absent. Caulis short, often broad. See Figure C6.
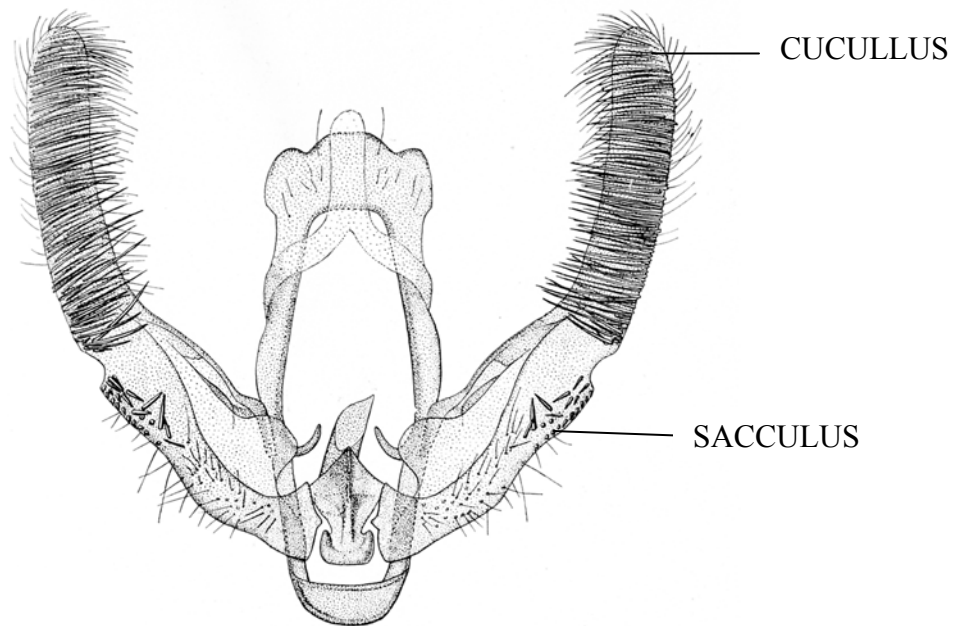
Figure C6. Ventral view of male genitalia [reproduced from Heinrich (1926)]

Female genitalia: [Description from Razowski (1989)]. Sterigma tubular, often
expanding anteriorly, ostium bursae somewhat asymmetrical, fused with subgenital
sternite by more or less elaborate membranous sac; colliculum very slender, marked by
weak inner sclerite, or not differentiated; ductus seminalis posterior; single, plate-shaped,
folded longitudianlly signum, if present. Seventh sternite with convex median part of
posterior edge and produced corners, folding sublaterally to form a pair of inner lobes
directed proximally. See Figure C7.

According to Razowski "The supposed autopomorphies of *Lobesia* are the fusion of the
anterior part of the sterigma with the posterior edge of the subgenital sternite and the
shape of the latter".
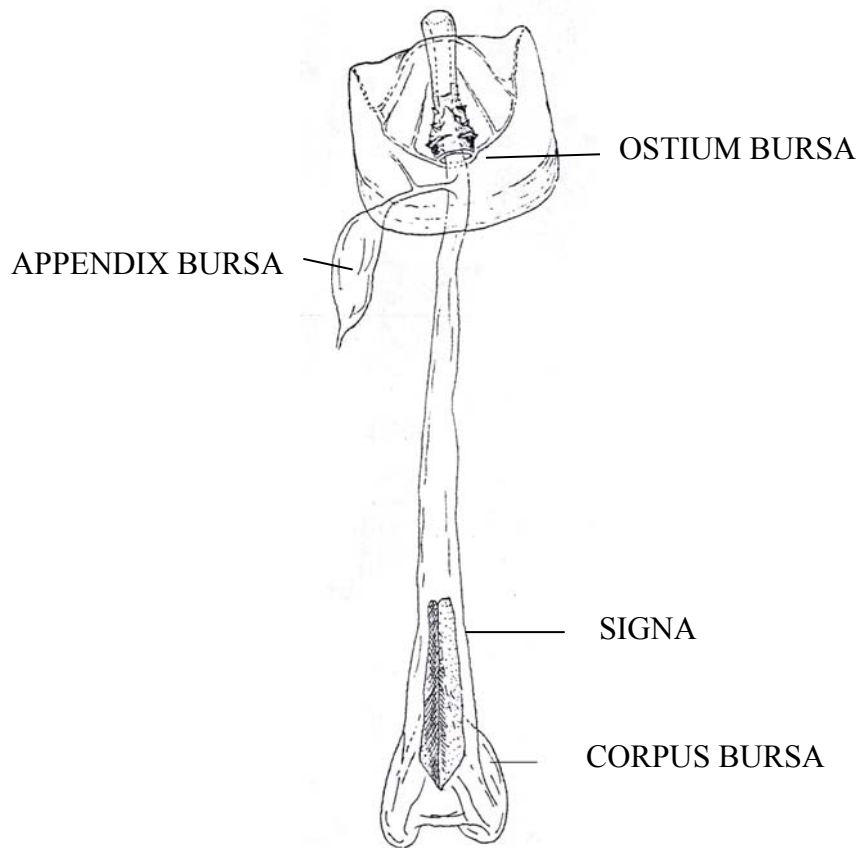
Figure C7. Ventral view of female genitalia [Reproduced from Razowski (1989).]

N.B. I was not able to locate illustrations that would have more clearly shown the morphological features discussed in the description. Consulting Klots, A.B. (1970). (Lepidoptera *In* Taxonomist's Glossary of Genitalia in Insects. Ed. S. Tuxen. Munksgaard, Copenhagen) may prove useful in understanding the nomenclature and morphology of lepidoptera genitalia. The Torre-Bueno Glossary of Entomology will also be a useful source for understanding nomenclature.

Similar species:

Lobesia occidentalis (male)   *Lobesia occidentalis* (female)

Lobesia occidentalis (Falkovitsh)-forewing generally dark brown mixed with yellow, the moderately conspicuous yellowish dorsal blotch and the dark hindwing distinguishes *occidentalis* from other *Lobesia* species**.**

Lobesia relinqua (male)   *Lobesia relinqua* (female)

Lobesia reliquana (Hübner)-Fore- and hindwings narrow and sharply angular; forewing triangular with general ferruginious coloration with white, apical black dorsal patch; male further distinguished by white, apically infuscate hindwing

Appendix D. Biology of *Lobesia botrana*

Population phenology
Lobesia botrana has two to four generations annually, but under optimal conditions an incomplete fifth generation can occur (Roehrich and Boller 1991, Roditakis and Karandinos 2001). The number of generations is determined by several factors including photoperiod, temperature, humidity, latitude, food quality, and the effects of predators and diseases (Deseo et al. 1981, Gabel 1981, Gabel and Mocko 1984a). Temperature and photoperiod are the most important factors in the development of *L. botrana*. However, both humidity and temperature simultaneously influence development (Ali et al. 1978a, Abashidze 1991), particularly at the microclimate level (Reichart (1968) in Deseo et al (1981)). Even under optimal temperature and humidity conditions, low reproduction can occur, suggesting that diapause and unknown factors may also strongly influence population dynamics (Deseo et al. 1981).

In response to differences in climate, the number of generations completed by *L. botrana* differs geographically. In general, more generations are completed in southern latitudes than in northern latitudes. For example, two generations occur annually in colder areas of Europe whereas this species typically has three generations in southern Europe. In Egypt, three generations occur, one in spring and two in summer (Ali et al. 1978b). Up to four generations can be completed in warmer regions such as Greece (Moschos et al. 1998). Under warm temperatures (30-32°C) and moderate relative humidity (40-45%), a generation can be completed within 30 to 32 days (eggs: 8-10 days; larvae: 17-18 days; pupae: 7-8 days) (Eghtedar 1996). Growth and development for *L. botrana* is considered "low" in cold areas (12.0-16.2°C); "favored" in temperate zones (16.2-26.7°C), proliferent at 26.7-29.5°C; and suboptimal in warmer zones (29.5-31.6°C) (Filip 1983). Table D1 provides a general phenological model for *L. botrana* based on accumulation of degree-days above a minimum threshold of 10°C and below a maximum threshold of 30°C (Caffarelli and Vita 1988). Accumulation of heat units begins January 1. Degree-days calculations are based on the sine method.

Table D1. Cumulative degree-days for three grapevine moth generations [reproduced from Caffarelli and Vita (1988); SE calculated from authors' data].

Phenological stage	Mean (± SE)
First generation:	
First catches	150 ± 7.7
Flight peak	236 ± 8.1
First eggs	301 ± 27.5
Second generation:	
First catches	699 ± 19.1
Flight peak	782 ± 19.1
First eggs	727 ± 13.6
100% hatch	869 ± 14.4
Third generation	
First catches	1,309 ± 20.1
Flight peak	1,462 ± 36.4

Phenological stage	Mean (± SE)
First eggs	1,304 ± 36.6
100% hatch	1,579 ± 16.1

Lobesia botrana is generally active from early spring to mid-late summer. In the central Jordan Valley where four generations occur per year, the first generation begins in mid-February and the fourth begins in early September and ends by mid-November (Al-Zyoud and Elmosa 2001). In Central Europe, development of *L. botrana* begins approximately on March 5 and ends around November 11, unless the developmental temperature threshold is not reached (Gabel and Mocko 1984a).

The size of the population varies substantially in each generation. The first generation is frequently the largest (though not necessarily the most economically damaging) and the third generation is often the smallest. This variation may be due to generational variation in female fecundity (Ali et al. 1978b). By the third generation, larval numbers decrease steadily, perhaps due to a lower temperature, the influence of diapause cues, or limited available food following the grape harvest (Ali et al. 1978b).

Stage specific biology
Adults of the first generation emerge when air temperature exceeds the threshold of 10˚C for a period of 10 to 12 days (USDA 1985, PPQ 1993). Emergence occurs over several weeks (Avidov and Harpaz 1969). Moths have appeared prior to the fruiting stage of grapes early in March, suggesting that the first generation is completed on another host (Genduso 1985, Al-Zyoud and Elmosa 2001). Adult female moths mate usually once (but often more than once), and males multiple times (Deseo et al. 1981, Torres-Villa et al. 1995, Torres-Vila et al. 1996, Torres-Vila et al. 1997, Torres-Villa et al. 1997, Torres-Villa et al. 2002b, Torres-Villa et al. 2002a). Mating occurs during flight (Avidov and Harpaz 1969). Females begin oviposition from one to three days after mating (Avidov and Harpaz 1969, USDA 1985).

High temperature and low humidity provide optimal conditions for moth activity, while rainy conditions along with low temperature seem to reduce the frequency of mating and, subsequently, egg production (Deseo et al. 1981). Optimal conditions for moth activity occur at temperatures over 20°C and at 40-70% relative humidity (Roehrich and Boller 1991). Heavy rain during the winter may delay reproduction until the following season (Avidov and Harpaz 1969, USDA 1985). Windy and wet conditions also tend to reduce flight activity. Moths prefer hot, sunny locations sheltered from wind, so flight paths generally lie between windbreaks (Avidov and Harpaz 1969, USDA 1985). Flight typically occurs at night from dusk to dawn and at temperatures over 12˚C, or when moths are disturbed (Avidov and Harpaz 1969). Moths feed on nectar (Avidov and Harpaz 1969). Under laboratory conditions, high relative humidity was shown to increase moth lifespan and egg-laying of *L. botrana* (reviewed in (Deseo et al. 1981).

At different geographical locations, fecundity under field conditions varies widely. Egg-laying is strongly affected by temperature (Deseo et al. 1981). Temperatures experienced by larvae during development affect adult oviposition (Rapagnani et al.

1989). About 35 eggs are laid per day, for a total of over 300 (Avidov and Harpaz 1969, Bradley et al. 1979b, USDA 1985, PPQ 1993). From Italian vineyards, Deseo et al. (1981) reported a mean of 78, 87 and 140 eggs per female during the first through third flights, respectively. Similarly, fecundity varied between generations, with a mean 76.7, 139.6 and 91.1 eggs/female in generations 1-3, respectively (reviewed by Deseo et al. (1981)). Under laboratory conditions, adults from larvae fed an artificial diet, laid an average of 75 eggs/day under optimal conditions, and 135 eggs/day on a diet of fall-harvested grapes under the same conditions (Deseo et al. 1981). Egg-laying can occur at temperatures ranging from 13-34.5°C, though it was observed that optimal temperature range for oviposition was 21-25°C, and fecundity decreased below 15°C (reviewed in Deseo et al. (1981)). The lower temperature of the optimum range is somewhat "flexible" (reviewed in Deseo et al. (1981)). Not only do cool temperatures negatively affect adults immediately, but a decline in adult numbers can continue following a cold period (Deseo et al. 1981). The adult and egg stages are considered the most vulnerable to environmental factors (Deseo et al. 1981).

Eggs are deposited in groups of 2 or 3 on or near the buds, pedicels, and flowers of grapevine in early spring or singly on the fruit of the host plant as the growing season progresses. Oviposition occurs within a day or two after females have mated. The incubation period in spring is approximately 7-11 days, compared to 3-5 days during the summer (Avidov and Harpaz 1969, Deseo et al. 1981, USDA 1985). Survival is affected by the host plant and the plant part chosen for oviposition, as both relate to food quality (Deseo et al. 1981, Gabel and Roehrich 1995). In laboratory studies, egg incubation lasted 4-6 days [at an unspecified temperature](Velimirovic 1975). Another laboratory showed the incubation period is reduced by an increase in temperature (Ali et al. 1978a) and is increased by high relative humidity (~55%) (Ali et al. 1978a)(Deseo, 1981 #1082). A "low" (unspecified) relative humidity can kill eggs (Coscolla et al. 1986, Roehrich and Boller 1991).

Larvae First generation larvae feed on buds and flowers and later pupate within rolled leaves or clusters of inflorescences (called glomerules) tied with silk (PPQ 1993, Fowler and Lakin 2002). Second generation larvae feed on and develop within single grapes, while subsequent generations can feed on several berries (PPQ 1993). The larval stage is reached after 4-5 weeks in spring and 2-3 weeks in summer (Avidov and Harpaz 1969, USDA 1985). In a laboratory study, larval development was complete between 15-27 days (Velimirovic 1975). Cool and rainy weather may adversely affect larvae, much like adults (Deseo et al. 1981).

Pupae The biology of pupae depends on whether individuals are in diapause or not. Diapausing pupae may be found under leaf litter, in soil crevices or under grapevine bark (Ali et al. 1978b, Bradley et al. 1979b, Roehrich and Boller 1991, PPQ 1993, Eghtedar 1996, Fowler and Lakin 2002). Non-diapausing pupae are typically found in rolled leaves (Fowler and Lakin 2002). Pupation on leaves of the host plant takes approximately 12 to 14 days (Briere and Pracros 1998, Fowler and Lakin 2002), though longer developmental times (9-12 weeks) have been noted for the spring generation (USDA 1985). Under warmer temperatures, non-diapausing pupae can complete development in 6-10 days in the laboratory (Velimirovic 1975, Briere and Pracros

1998). This estimate agrees with pupal development rates observed for *L. botrana* in the summer (USDA 1985). Pupae occurring late in summer or early fall typically overwinter but also may contribute to an additional, partial generation (Avidov and Harpaz 1969, Ali et al. 1978b, Bradley et al. 1979b, PPQ 1993). *Lobesia botrana* overwinter as diapausing pupae.

Diapause in *L botrana* is facultative and occurs during the pupal stage. Diapause induction begins when eggs or young larvae are exposed to a critical photoperiod (Deseo et al. 1981, Gabel and Mocko 1984a, Roehrich and Boller 1991). The critical diapause-inducing photoperiod is approximately 13 hours at 25-26°C; while a longer photoperiod at constant colder temperature (22°C) did not induce diapause (Deseo et al. 1981). Under field (vineyard) conditions, the photoperiod necessary to induce diapause was approximately 15 hours (Deseo et al. 1981). In laboratory studies, the critical photoperiod is approximately 15 hours + 42.5 minutes of light (Gabel and Mocko 1984a). Temperatures just below 10°C are optimal for diapause development, however temperatures under 8°C during post-diapause development can cause death (Roehrich and Boller 1991). Under laboratory conditions diapause lasts approximately 5.5-6 months, regardless of temperature (Deseo et al. 1981, USDA 1985).

Table D2 provides results from several studies to describe the developmental temperature threshold and degree-days needed for the completion of each life stage.

Table D2. Developmental threshold and degree day requirements for *Lobesia botrana*.

Stage	Developmental threshold (°C)	Degree Days	Notes	Reference
Egg	0.7	101±3.3	from authors' Table 1	(Ali et al. 1978a)
	8.8	74.0±2.3		(Gabel 1981, Gabel and Mocko 1984a)
	9.4	88.8 ± 3.2	from authors' Table 1 & 2	(Briere and Pracros 1998)
	10	75		(Bloesch and Siebenthal 1988, Roehrich and Boller 1991)
	10	56		(Filip 1983)
	10	66±17.9		(Abashidze 1991)
	12	120	First generation; cage study	(Popov, 1975 cited in (Zeki 1996))
	12	520	Second generation; cage study	(Popov, 1975 cited in (Zeki 1996))
Larva	6.5	127.2 ± 4.9	5th instar on diet	(Briere and Pracros 1998)
	7.3	384.6±30.1	males	(Gabel 1981, Gabel and Mocko 1984a)
	7.3	62.9 ± 1.3	3rd instar on diet	(Briere and Pracros 1998)
	8.2	64.7 ± 2.3	4th instar on diet	(Briere and Pracros 1998)

Stage	Developmental threshold (°C)	Degree Days	Notes	Reference
	8.4	55.9 ± 2.8	2nd instar on diet	(Briere and Pracros 1998)
	9.2	65.5 ± 6.3	1st instar on diet	(Briere and Pracros 1998)
	9.2	320.6 ± 14.6	1st to 5th instars on diet	(Briere and Pracros 1998)
	9.4	362.3±20.9	females	(Gabel 1981, Gabel and Mocko 1984a)
	10	170	on flower clusters	(Roehrich and Boller 1991)
	10	225	on grape berries	(Roehrich and Boller 1991)
	10	81±8.4		(Abashidze 1991)
	10.7	290±27	from authors' Table 2	(Ali et al. 1978a)
	13.2	216		(Filip 1983)
Pupa	7.1	162.1±23.5	male	(Gabel 1981, Gabel and Mocko 1984a)
	8	64		(Filip 1983)
	9.1	151.5±24	females	(Gabel 1981, Gabel and Mocko 1984a)
	10	130		(Roehrich and Boller 1991)
	10	351±81	diapauses as pupa	(Abashidze 1991)
	10.3	130±4.0	from authors' Table 1	(Ali et al. 1978a)
Adult	10	61		(Abashidze 1991, PPQ 1993)
	11	not specified	males	(Gabel 1981)
	12	48		(Filip 1983)
	12.8	not specified	females	(Gabel 1981)
Adult-Pupa	10	402	1st generation on grapevine buds and flowers	(PPQ 1993)
	10	441	2nd generation on grapes	(PPQ 1993)
Egg-Adult	12	384		(Filip 1983)

Interactions

Temperature and Relative Humidity. Temperature extremes strongly affect *Lobesia botrana*. *Lobesia botrana* populations are generally denser in hotter, sunny areas or seasons (Gabel and Thiéry 1994a). Under temperature extremes, both larvae and eggs can become dormant (Gabel and Thiéry 1994b). High relative humidity with low temperatures has negative effects on insect development while positive growth occurs with moderate temperatures and humidity (Al-Zyoud and Elmosa 2001). Low

temperatures with high humidity and high temperatures with low humidity have negative effects on insect growth (Al-Zyoud and Elmosa 2001). The most favorable conditions for insect growth in warmer climates, such as Egypt, occurs with temperatures of 25-30˚C, accompanied by a relative humidity of 55-65% (Ali et al. 1978a, Al-Zyoud and Elmosa 2001).

Photoperiod. Photoperiod is the second most important factor affecting both the number of generations completed in a year and the number of pupae entering diapause (Gabel and Mocko 1984a, Gabel and Mocko 1984b). See studies by Deseo et al. (1981) and Gabel and Mocko (1984 a,b) for a more detailed description of the influence of photoperiod on *L. botrana* populations.

Water. In drier regions, a lack of water is thought to be a key factor in population dynamics, preventing *L. botrana* from achieving full reproductive potential. Reproductive potential of *L. botrana* with and without available water under laboratory conditions has been evaluated by Torres-Vila et al. (1996).

Biotic Factors. Biotic factors also play a role in population dynamics. Pathogens, parasites and predators can strongly influence *L. botrana* population dynamics, but the effects vary widely from generation to generation and from year to year and may help explain fluctuations under similar environmental conditions (Deseo et al. 1981, Al-Zyoud and Elmosa 2001). Rainy weather can also increase the dissemination of pathogens on the plant host where *L. botrana* becomes infected after feeding (Deseo et al. 1981).