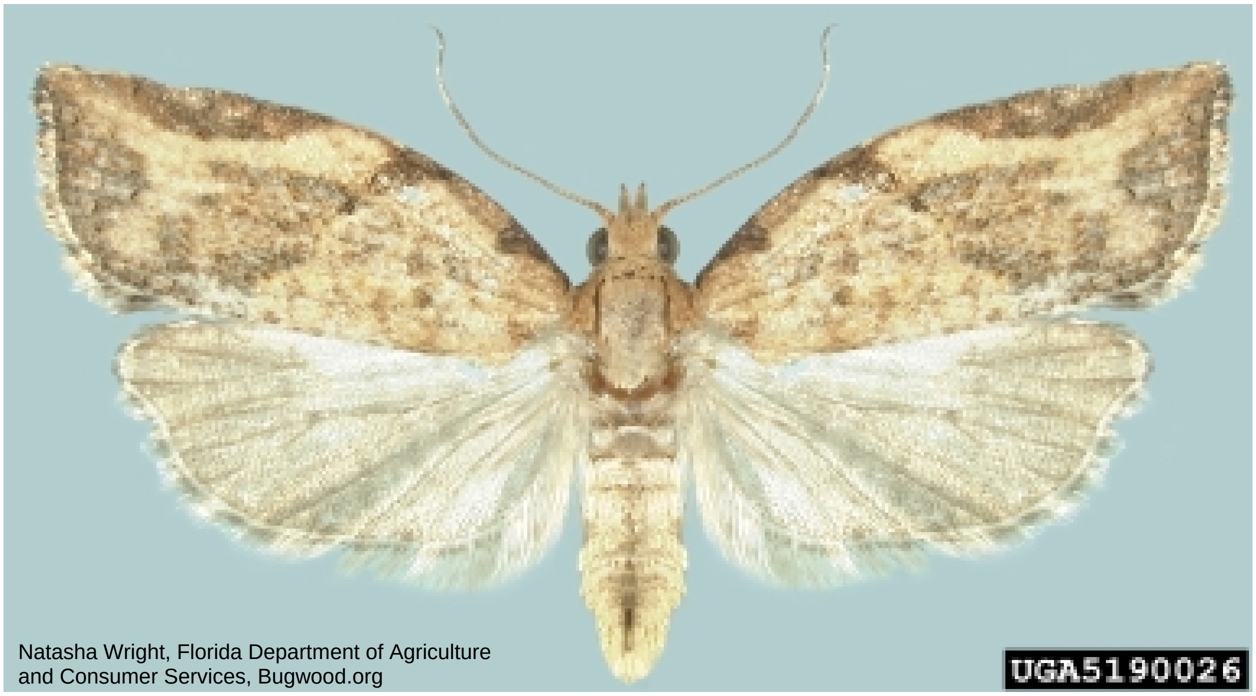
United States Department of Agriculture
Animal and Plant Health Inspection Service

Economic Analysis: Risk to U.S. Apple, Grape, Orange and Pear Production from the Light Brown Apple Moth, *Epiphyas postvittana* (Walker)

USDA-APHIS-PPQ-CPHST-PERAL

May 2009



Authors:
Glenn Fowler: Risk Analyst
Lynn Garrett: Economist
Alison Neeley: Risk Analyst
Roger Magarey: Senior Researcher
Dan Borchert: Risk Analyst
Brian Spears: Senior Risk Analyst

Agency Contact:
Dr. Glenn Fowler
1730 Varsity Drive Suite 300
Raleigh, NC 27606
Phone: 919-855-7511
Fax: 919-855-7599
Email: glenn.fowler@aphis.usda.gov

Rev. 05 052709

Executive Summary

We conducted this economic analysis at the request of USDA-APHIS-PPQ-EDP. Our objective was to quantitatively characterize the economic costs to apple, grape, orange and pear crops that would result from the introduction of the light brown apple moth (LBAM), *Epiphyas postvittana*, into the conterminous United States. This information can be used to inform regulatory policy and funding decisions regarding LBAM.

Our economic analysis had two components: 1) a geospatial analysis that identified areas at risk for LBAM establishment based on climate and hosts and 2) a quantitative analysis, using a probabilistic modeling approach, which estimated the economic losses LBAM could cause if introduced into these areas due to damage, control, quarantines and research. Economic effects outside of the agricultural crop (apple, grape, orange and pear) production sector, e.g. trade effects, are beyond the scope of this analysis and are not provided.

Our geospatial analysis estimated that LBAM could establish throughout the majority of the conterminous United States. This establishment range included the majority of the growing area for the analyzed crops.

Our quantitative model estimated the mean total annual costs if LBAM were introduced in the at-risk areas to be \$118 million. The 5th and 95th percentile values were: \$86 million and \$150 million, i.e. 95 percent of the time, total annual costs exceeded \$86 million.

The combined results of our geospatial and quantitative analyses indicate that LBAM could cause substantial economic losses to U.S. apple, grape, orange and pear crops if introduced throughout the conterminous United States. We note LBAM is highly polyphagous and would probably cause additional economic damage to other crops and sectors of the U.S. economy, e.g. domestic and international trade. Also, because LBAM can occur in nursery stock, this industry could provide another pathway for its introduction outside of the quarantined area in addition to movement on agricultural commodities.

Table of Contents

List of Tables

List of Figures

List of Appendices

I. Introduction

We conducted this economic analysis at the request of USDA-APHIS-PPQ-EDP. Our objective was to quantitatively characterize the annual economic costs that the light brown apple moth (LBAM), *Epiphyas postvittana*, could cause to U.S. apple, grape, orange and pear crops if it were to establish throughout its potential range in the conterminous United States. This information can be used to inform regulatory policy and funding decisions regarding LBAM.

LBAM is a polyphagous multivoltine tortricid moth (Johnson et al., 2007). It is a significant agricultural and nursery pest in Australia and New Zealand where it attacks a variety of hosts including: citrus, grapes, pome fruits and stone fruits. LBAM damages hosts by feeding on the leaves, fruit and stems and can cause both internal and external fruit damage. If left untreated, LBAM crop damage levels have been estimated to be as high as 40 to 90 percent (Sutherst, 2000).

In March of 2007, the USDA confirmed LBAM's presence in California (Johnson et al., 2007; USDA-APHIS, 2009, 2009a). Trapping evidence indicated that LBAM may have been present in California since 2006 (USDA-APHIS, 2007). The LBAM confirmation resulted in the implementation of a joint emergency response by the USDA, CDFA and affected counties. As of April 22, 2009, LBAM is considered present in 15 California counties and eradicated in Los Angeles County and San Luis Obispo County (Carpenter pers. comm., 2009; NAPIS, 2009; USDA-APHIS, 2009a) (Figure 1).

LBAM's detection in California has resulted in surveys, quarantines and aerial control programs. Because LBAM can be transported via agricultural and nursery stock pathways (Johnson et al., 2000; USDA-APHIS, 2007a), it has the potential to spread long distances outside of the quarantined area and cause additional economic losses. In this analysis we characterized the potential annual economic losses to U.S. apples, grapes, oranges and pears due to LBAM damage, control costs, quarantines and research if it were to be introduced into the conterminous United States. We did not analyze potential economic losses to sectors outside of agricultural production, e.g. trade.

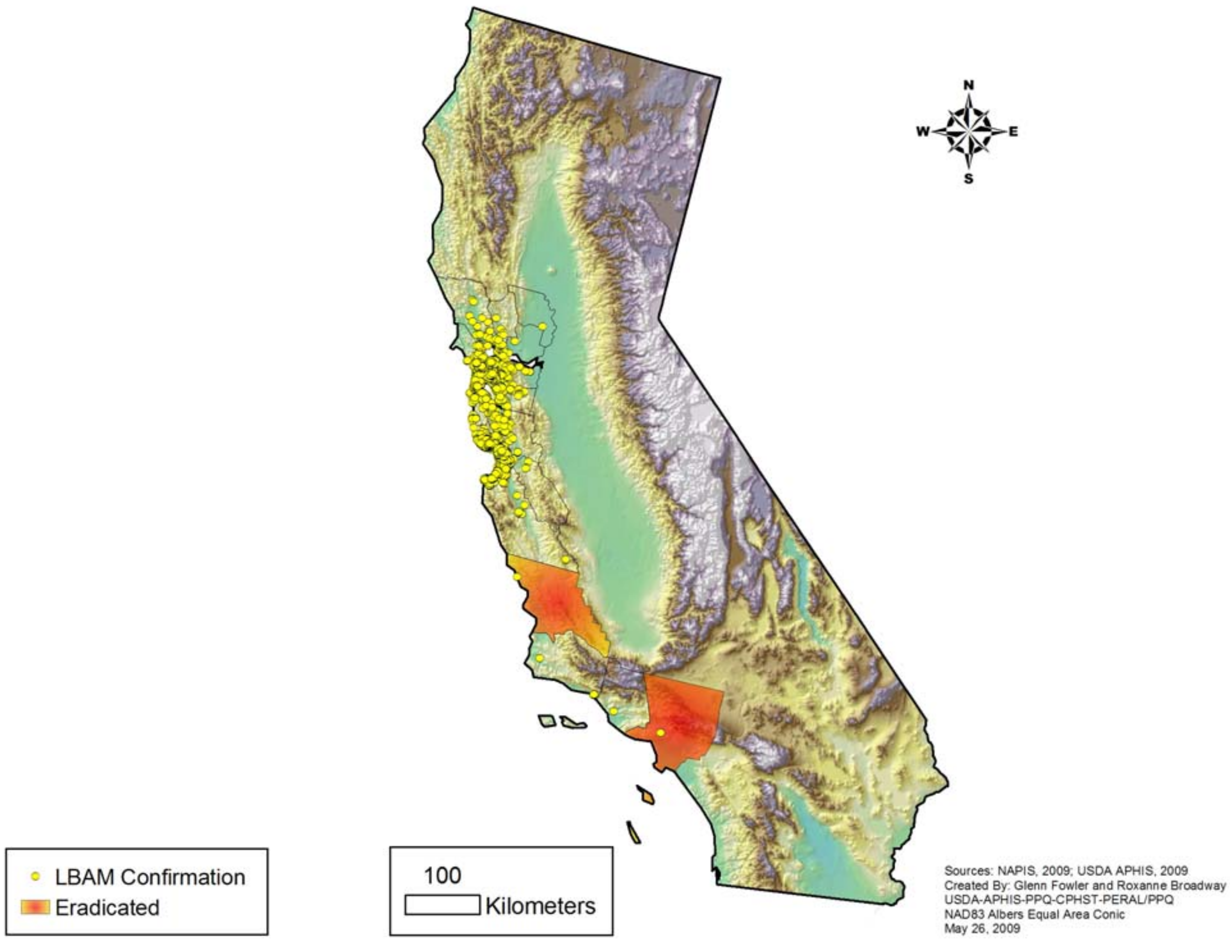


Figure 1. LBAM confirmations from 2007 to April 22, 2009.

II. Methods

In this analysis we characterized the risk, in terms of annual economic costs, posed by LBAM to apple, grape, orange and pear production in the conterminous United States. We chose these commodities because:

- data regarding LBAM's economic effects on them has been reported in Australia (Sutherst, 2000),
- LBAM is considered an economic pest on them with documented economic crop value losses identified and
- they are high value commodities covering a wide geographic production range in the United States (USDA-NASS, 2007, 2008, 2008a).

The methods used here can be adapted to other commodities if needed. Our economic analysis had two components: 1) a geospatial analysis that identified areas at risk for LBAM establishment and 2) a quantitative analysis that estimated the range of economic damage LBAM could cause if introduced into these areas.

A. Geospatial Analysis of U.S. At-Risk Areas Based on Climate and Hosts

We used Borchert's (2007) degree day (DD) model, which was generated using parameters from Danthanarayana (1975), to visualize areas where LBAM could establish based on climate. We considered areas where LBAM could complete at least three generations (≥ 2,221 DD at a base temperature of 7.5°C) to be at risk for permanent establishment based on its behavior in Australia (Borchert, 2007; CABI, 2006; Danthanarayana, 1975; Wearing et al., 1991). We simulated our DD model using the NAPPFAST (2009) system and ten year historical daily climatology (1999 to 2008) at a 10 km^2 resolution.

Based on the research of Gutierrez et al. (unpublished), we assumed areas where the minimum air temperature was ≤ -16°C for at least one day during the year were too cold for LBAM establishment. We modeled the occurrence of this lethal cold temperature using the NAPPFAST (2009) system and ten year historical daily climatology (1999 to 2008) at a 10 km^2 resolution.

We subtracted the lethal cold 10 year frequency of occurrence output from the three generation 10 year frequency of occurrence output. The resulting map visualized areas suitable to LBAM establishment in terms of suitability for three generation occurrence and non-lethal cold temperatures (Figure 2).

We geospatially visualized counties that intersected the climate match area for LBAM establishment with ArcGIS 9.3 (ESRI, 2008) (Figure 3). The use of ArcGIS reflects the expertise of the authors and should not be interpreted as product endorsement. The at-risk counties were joined to the apple, grape, orange and pear crop acreage data for 2007 and the crop acreage per county was geospatially visualized (USDA-NASS, 2007) (Figures 4 to 7).

B. Quantitative Economic Analysis

We constructed a quantitative model that characterized the economic damage that could occur if LBAM were introduced into at-risk areas in the conterminous United States (Appendices 8 and 9). Our model estimated the range of economic damage for each crop and the total for all four crops. In addition we quantitatively characterized the economic costs associated with quarantines and research.

Our model was comprised of steps, e.g. quantities and proportions, which were informed using scientific, economic and agricultural sources (Auclair et al., 2005). We used a PERT distribution to model step inputs. The PERT is a continuous distribution that is defined by a minimum, most likely and maximum value (Vose, 2000, Palisade, 2002). We chose the PERT because it concentrates values towards the center of the distribution which increases its objectivity and decreases the effects of extreme values (Auclair et al., 2005; Groenendaal, 2006; Vose, 2000).

To simulate the model we used @Risk 4.52 professional probabilistic modeling software (Palisade, 2002a). The use of @Risk reflects the expertise of the authors and should not be interpreted as product endorsement. We used Latin Hypercube sampling with a fixed random generator seed of one and 10,000 iterations in the model simulation settings.

We provided summary statistics for specified model outputs. We also reported the model outputs graphically using a cumulative distribution function (cdf). The cdf can be used to estimate the probability of being less than or equal to a value on the *x*-axis (Vose, 2000). This is done by moving vertically up from the *x*-value to the graph intercept and horizontally left to the associated probability on the *y*-axis.

1. Quantitative Model

Step 1. Crop production value in the LBAM at-risk areas

We first summed each crop's 2007 bearing acreage in at-risk counties for each affected state and divided this value by the total state 2007 bearing acreage for each crop (USDA-NASS, 2007). This proportion was multiplied times the total value of each state's crop in 2007 to estimate the economic value of each crop in the at-risk counties (USDA-NASS, 2008) (Appendices 1, 2 and 4). For some states, the 2007 bearing acreage and/or crop values were not reported by the National Agricultural Statistics Service (USDA-NASS, 2007, 2008). We estimated the crop values for at-risk counties in those states based on their at-risk county bearing acreage in 2007 and the ratio of U.S. bearing acreage to U.S. crop value in 2007. For oranges, all of the U.S. production counties were at risk and we used the total U.S. 2007 orange crop value in this step (USDA-NASS, 2008a) (Appendix 3).

We then converted the 1998 to 2006 annual crop values into 2007 dollars (Appendix 5) (USDA-NASS, 2000, 2000a, 2002, 2002a, 2004, 2005, 2006, 2008, 2008a). Using the ratio of 2007 at-risk county crop values to total 2007 U.S. crop values (NASS, 2008, 2008a), we estimated the at-risk county crop values from 1998 to 2006. We used the minimum, mean and maximum values from the resulting 10 year data set in the PERT distribution for each crop (Table 1).

Step 2. Proportion of crop value damaged by LBAM

We modeled this step by dividing the LBAM damage and control costs of each crop, for the 1993/1994 production year, in five Australian States by the total economic value of each crop in each state for the 1993/1994 production year (McLennan, 1995; Sutherst, 2000) (Table 1; Appendix 6). We used the resulting minimum, mean and maximum proportions, for each crop in the five state data set, as parameters in the PERT distribution (Table 1).

Step 3. Estimated crop damage costs in the LBAM at-risk areas

This value was equal to the product of steps 1 and 2 for each crop.

Step 4. Total estimated crop damage costs in the LBAM at-risk areas

This value was equal to the sum of the damage costs for all four analyzed crops from step 3.

Step 5. Relative proportion of total estimated crop damage costs due to quarantines in LBAM at-risk areas

We estimated the potential costs of quarantines if LBAM were introduced into the U.S. at-risk areas using data from Australia (Sutherst, 2000). There is uncertainty regarding this estimate because LBAM could exhibit different relative quarantine costs in the United States. During the 1993/1994 production season, the LBAM quarantine costs in five Australian States for apples, grapes, oranges and pears was 8 percent of the total LBAM crop damage costs for these crops. We used this proportion as the most likely value in the PERT distribution. We assumed a normal distribution and estimated the minimum and maximum values for the PERT distribution based on the 99 percent confidence interval values (Caton pers. comm., 2007; Cochran, 1977) (Table 1; Appendices 7, 10 and 11).

Step 6. Estimated quarantine costs in the LBAM at-risk areas

This value was equal to the product of steps 4 and 5.

Step 7. Relative proportion of total estimated crop damage costs due to research in the LBAM at-risk areas

We estimated the potential costs of research if LBAM were introduced into the at-risk areas using the methodology for the proportional quarantine cost estimate. Similarly, there is uncertainty regarding this estimate due to potential differences in relative research costs between the United States and Australia. During the 1993/1994 production season, the LBAM research costs in five Australian States was 4.8 percent of the total LBAM crop damage costs to apples, grapes, oranges and pears. We used this proportion as the most likely value in the PERT distribution. We assumed a normal distribution and estimated the minimum and maximum values for the PERT distribution based on the 99 percent confidence interval values as above (Table 1; Appendices 7, 12 and 13).

Step 8. Estimated research costs in the LBAM at-risk areas

This value was equal to the product of steps 4 and 7.

Step 9. Total estimated costs in the LBAM at-risk areas

This step estimates the total costs from crop damage, control, quarantines and research if LBAM were introduced into the at-risk areas within the conterminous United States. It is equal to the sum of steps 4, 6 and 8.

Table 1. PERT distribution input parameters used in the model.

Step	Description	Crop	Minimum	Most Likely	Maximum
1	Annual crop value	Apples	916,618,143	1,112,091,696	1,494,956,244
		Grapes	2,880,829,971	3,323,742,419	3,600,086,795
		Oranges	1,554,609,000	2,001,627,700	2,490,224,000
		Pears	214,199,688	239,961,754	268,654,213
2	Proportion of crop damaged	Apples	0.003	0.020	0.040
		Grapes	0.001	0.010	0.015
		Oranges	0.007	0.023	0.036
		Pears	0.003	0.021	0.035
5	Quarantine Costs Proportion	All four crops	0.010	0.080	0.150
7	Research Costs Proportion	All four crops	0.000	0.048	0.103

III. Results and Discussion

Our geospatial analysis estimated that LBAM could establish throughout the majority of the conterminous United States with the West Coast, Southwestern and Southeastern States at highest risk (Figures 2 to 7). This establishment range captures the majority of the growing areas for the analyzed crops. The percentage of the annual crop value produced within the at-risk areas were: apples (58%), grapes (97%), oranges (100%) and pears (73%) (Appendix 5).

Our quantitative model estimated the total annual crop costs due to damage and control if LBAM were introduced in the at-risk areas (Table 2; Figures 8 and 10). The 5th, mean and 95th percentile values were: \$76,688,000; \$104,281,000 and \$132,407,000. The crops listed in descending order of economic loss and percentage of total crop damage costs were: oranges (43%), grapes (30%), apples (22%) and pears (5%). The 5th, mean and 95th percentile values for the total annual estimated costs with the addition of quarantines and research were: \$86,103,000; \$117,751,000 and \$150,400,000 (Table 2, Figures 9 and 10).

The combined results of our geospatial and quantitative analyses indicate that LBAM could cause substantial economic losses to U.S. apple, grape, orange and pear crops if introduced into the conterminous United States. We note LBAM is highly polyphagous (CABI, 2006; Johnson et al., 2007) and would probably cause additional economic damage to other crops and sectors of the U.S. economy, e.g. domestic and international trade. Also, because LBAM can occur in nursery stock, this industry could provide another pathway for its introduction outside of the quarantined area in addition to movement on agricultural commodities (Johnson et al., 2007; USDA-APHIS, 2007a).

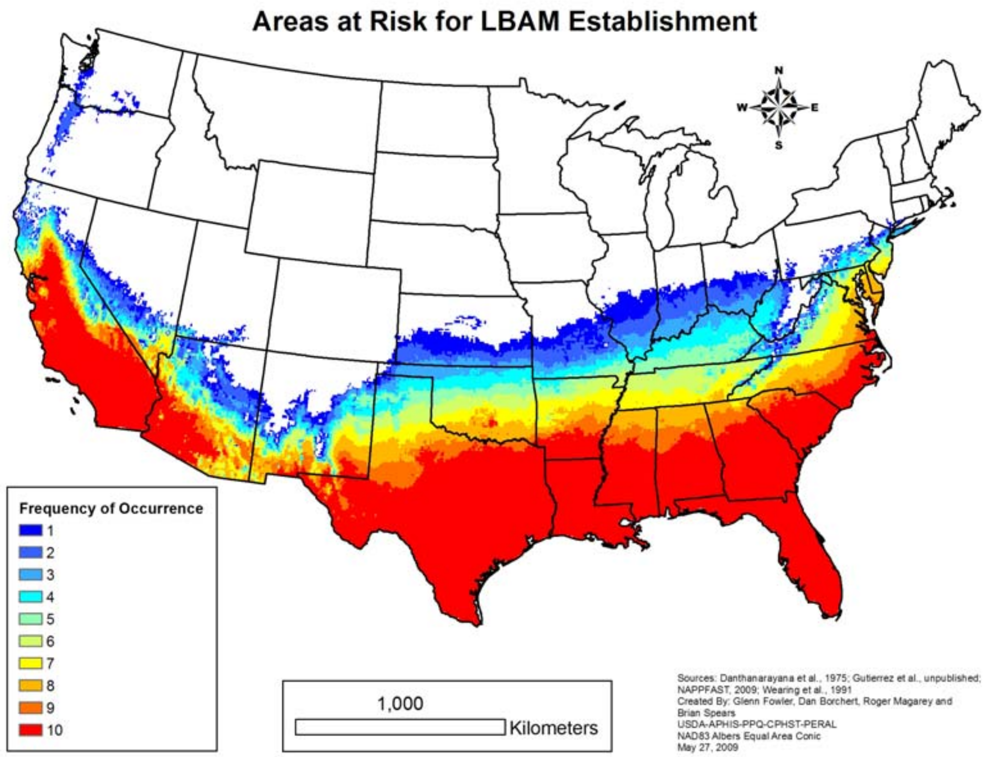


Figure 2. Climate match analysis for areas at risk for LBAM establishment. The results are reported in terms of frequency of years from 1999 to 2008 where enough degree days accumulated for LBAM to complete ≥ three generations and non-lethal minimum daily temperatures >-16°C occurred.

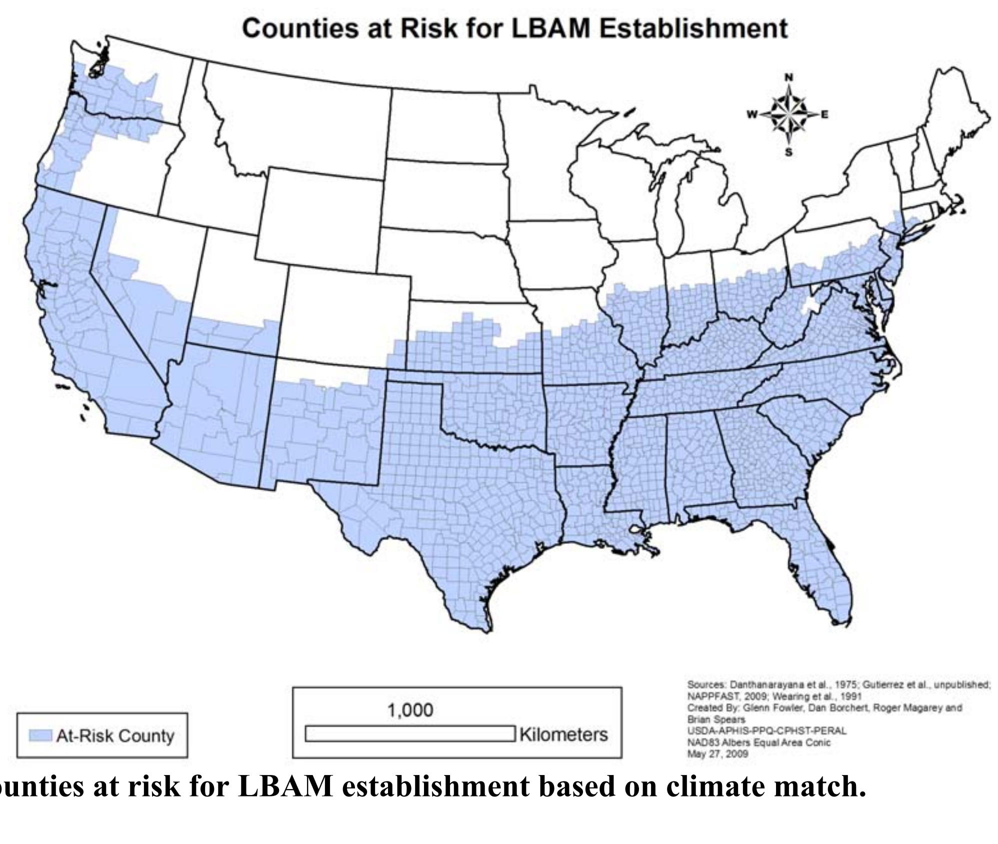


Figure 3. Counties at risk for LBAM establishment based on climate match.

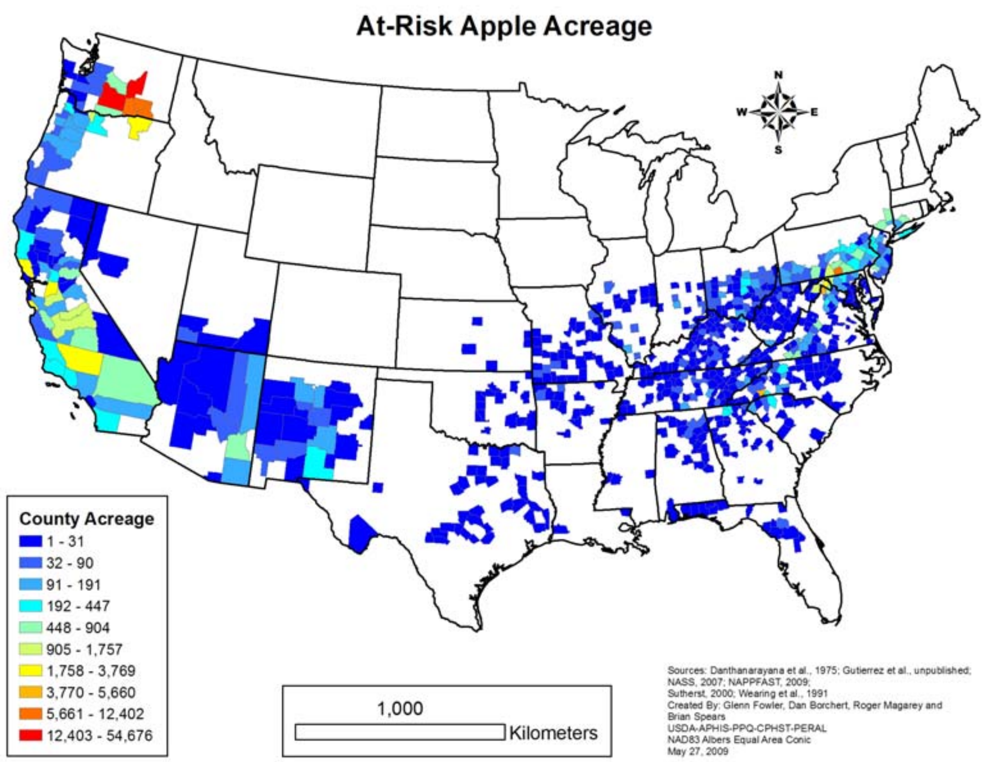


Figure 4. Apple acreage in counties at risk for LBAM establishment.

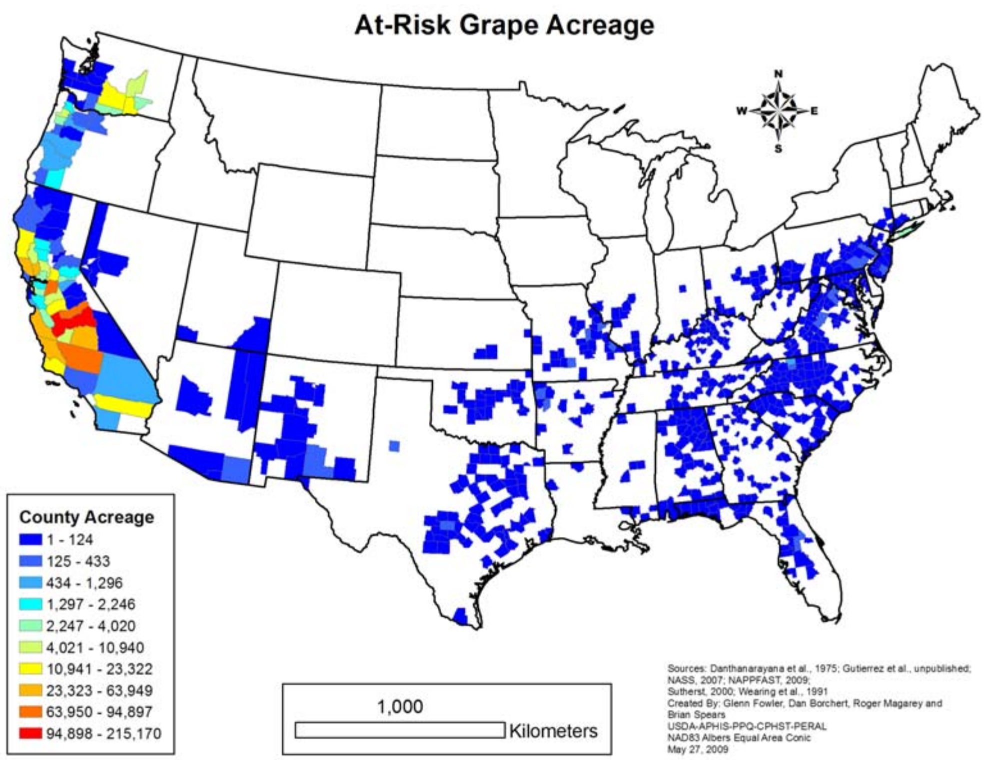


Figure 5. Grape acreage in counties at risk for LBAM establishment.

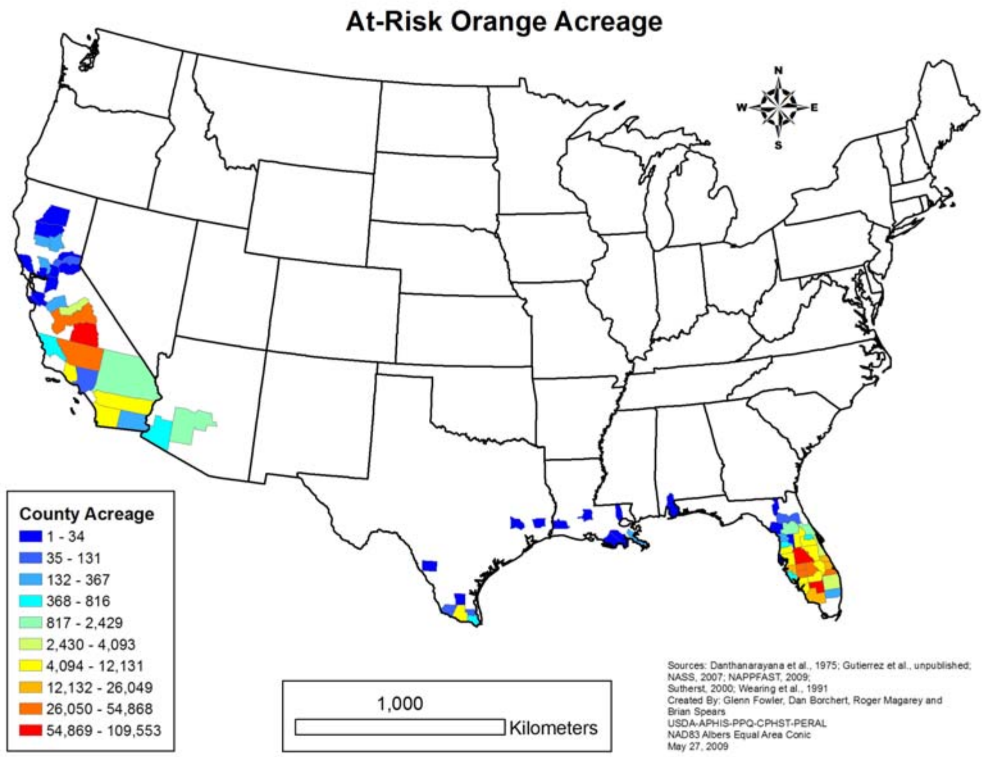


Figure 6. Orange acreage in counties at risk for LBAM establishment.

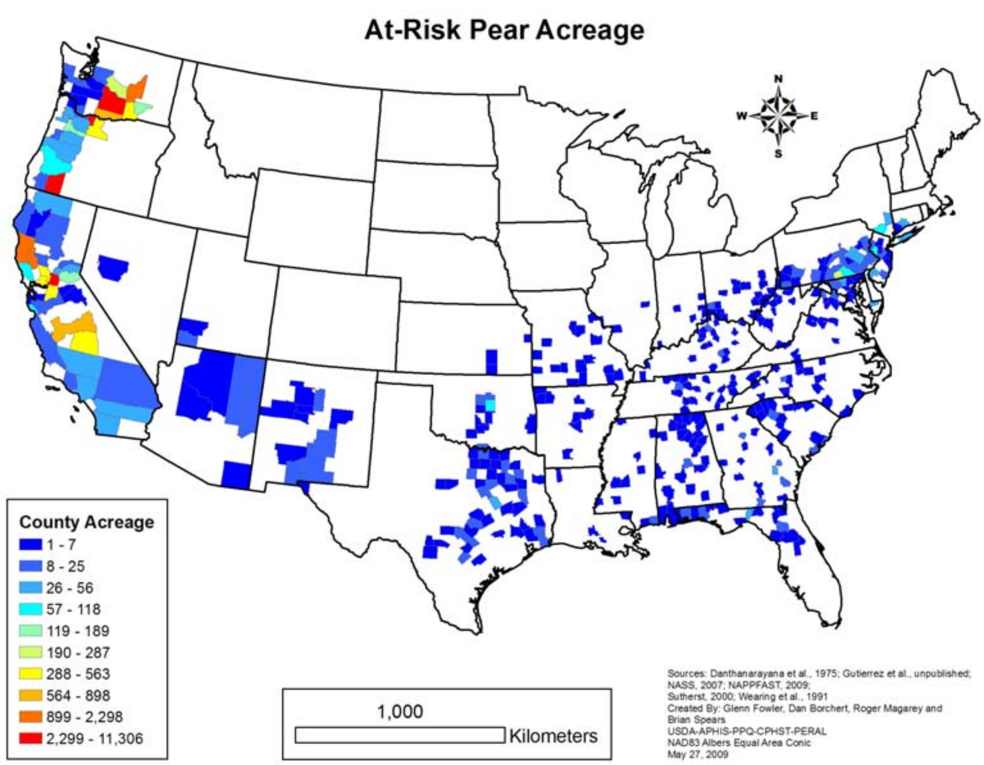


Figure 7. Pear acreage in counties at risk for LBAM establishment.

Table 2. Model outputs for estimated LBAM annual economic costs if introduced into areas at risk for establishment. Because each item is a separate output the total costs will not equal the sum of the other costs.

Item	5th Percentile	Mean	95th Percentile
Apple	10,351,000	23,437,000	37,721,000
Grape	15,781,000	30,760,000	44,225,000
Orange	26,163,000	45,194,000	64,904,000
Pear	2,431,000	4,890,000	7,234,000
Total Crop Costs	76,688,000	104,281,000	132,407,000
Quarantine Costs	3,566,000	8,342,000	13,819,000
Research Costs	1,765,000	5,129,000	9,026,000
Total Costs	86,103,000	117,751,000	150,400,000

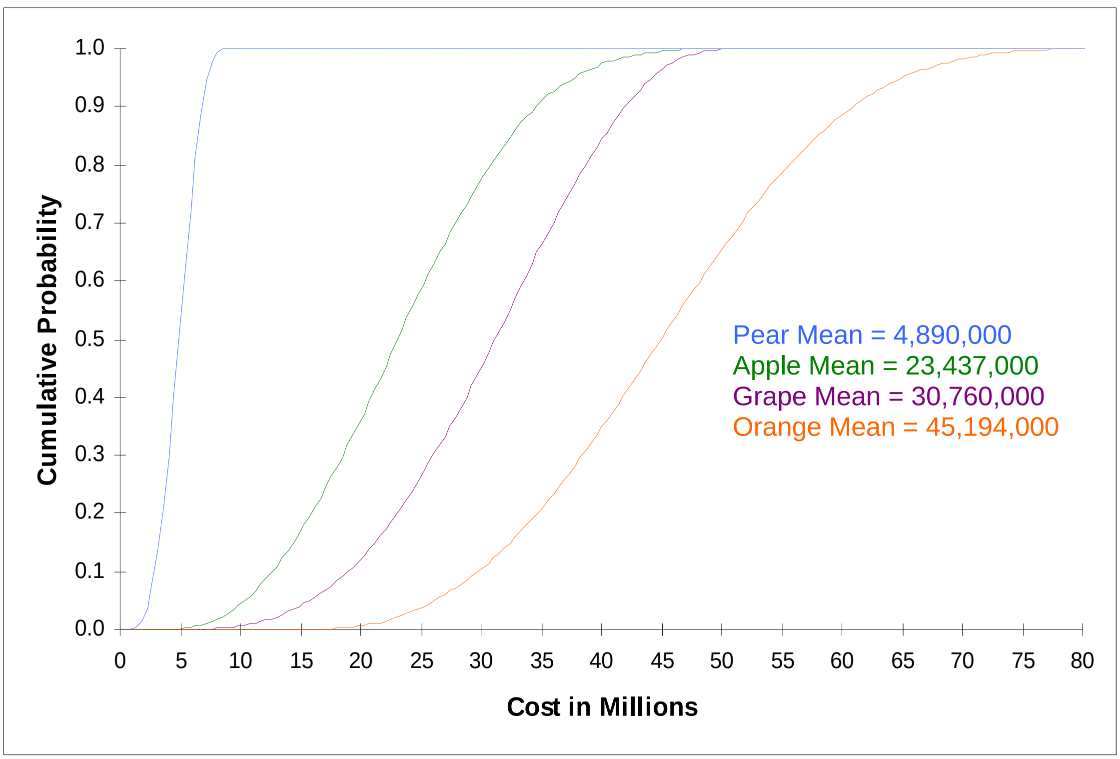


Figure 8. Cumulative distribution functions for estimated annual costs to apples, grapes, oranges and pears if LBAM were introduced into at-risk areas.

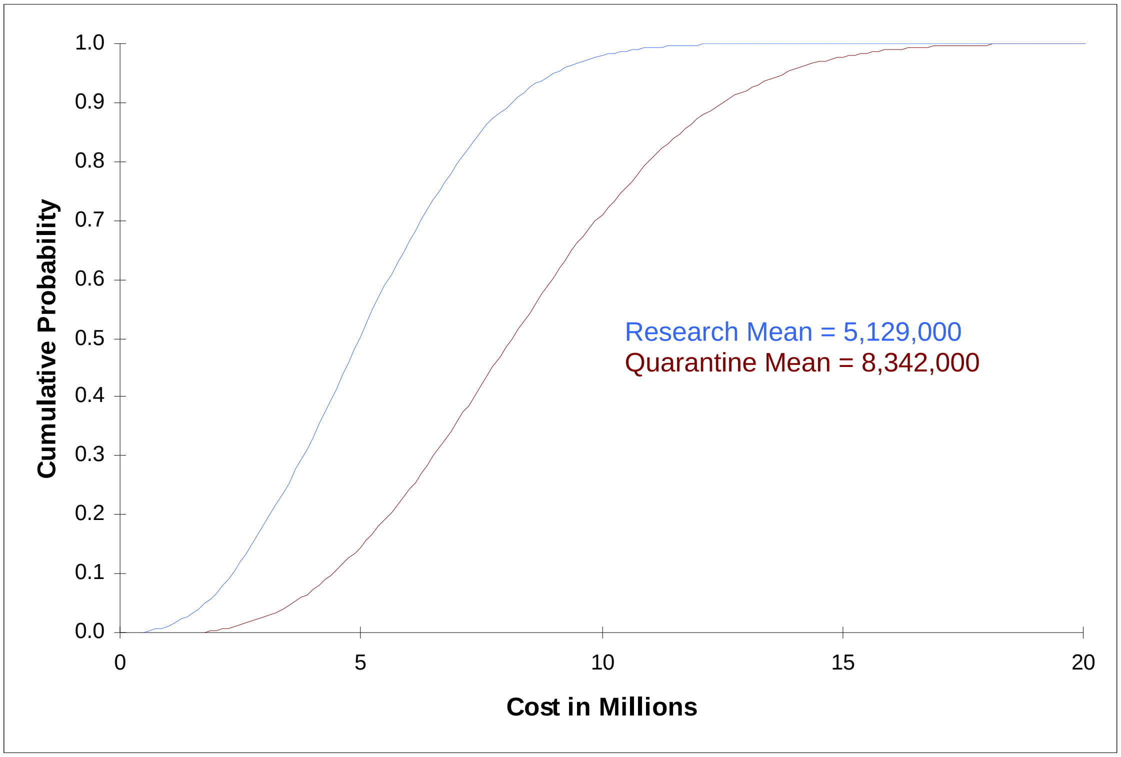


Figure 9. Cumulative distribution functions for estimated annual quarantine and research costs if LBAM were introduced into at-risk areas.

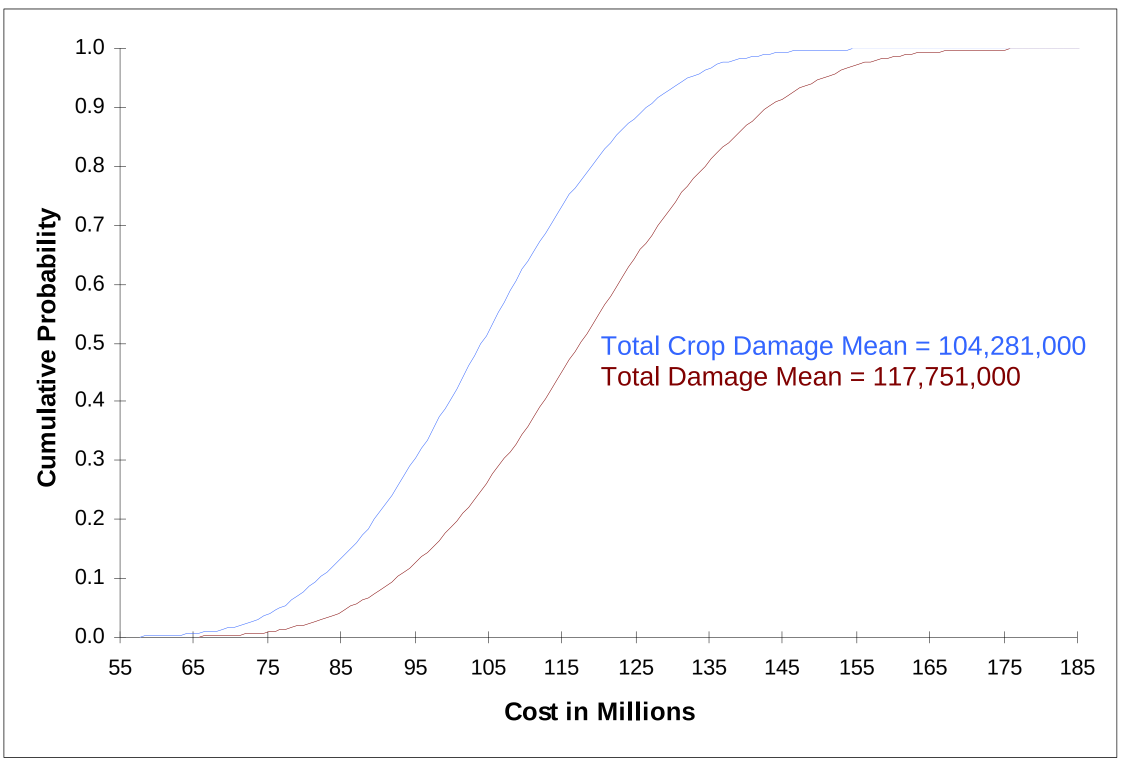


Figure 10. Cumulative distribution functions for estimated total annual crop damage and total annual costs if LBAM were introduced into at-risk areas.

IV. Reviewers

Robert Griffin: Director; USDA-APHIS-PPQ-CPHST-PERAL
Barney Caton: Assistant Director; USDA-APHIS-PPQ-CPHST-PERAL
Parveen Setia: Chief, Policy Analysis and Development; USDA-APHIS-PPD

V. Acknowledgements

Roxanne Broadway: USDA-APHIS-PPQ
Gary Carpenter: USDA-APHIS-PPQ
Thomas Culliney: USDA-APHIS-PPQ
Ashley Jackson: USDA-APHIS-PPQ

VI. Literature Cited

Auclair, A.N.D.; Fowler, G.; Hennessey, M.K.; Hogue, A.T.; Keena, M.; Lance, D.R.; McDowell, R.M.; Oryang, D.O. and Sawyer, A.J. 2005. Assessment of the risk of introduction of *Anoplophora glabripennis* (Coleoptera: Cerambycidae) in municipal solid waste from the quarantine area of New York City to landfills outside of the quarantine area: a pathway analysis of the risk of spread and establishment. Journal of Economic Entomology. 98 (1):47-60.

Borchert, D. 2007. Risk analyst. USDA-APHIS-PPQ-CPHST-PERAL. Raleigh, North Carolina.

CABI. 2006. Crop protection compendium, 2006 ed. Wallingford, U.K.: CAB International [CD-ROM].

Carpenter, G. 2009. United States Department of Agriculture. Animal and Plant Health Inspection Service. Fort Collins, Colorado.

Caton, B. 2007. Assistant Lab Director. Plant Epidemiology and Risk Analysis Laboratory. USDA-APHIS-PPQ-CPHST-PERAL. Raleigh, North Carolina.

Cochran, W.G. 1977. Sampling techniques. 3rd ed. Wiley. New York. 428 pp.

Danthanarayana, W. 1975. The bionomics, distribution and host range of the light brown apple moth, *Epiphyas postvittana* (Walk.) (Tortricidae). Australian Journal of Zoology. 23(3): 419-437.

ESRI. 2008. Environmental Systems Research Institute. Redlands, California. www.esri.com

Groenendaal, H. 2006. Introduction to quantitative analysis. Vose Consulting. Princeton, New Jersey. June 7 to 9.

Gutierrez, A.P.; Mills, N.J. and Ponti, L. Unpublished. Climatic limits of the light brown apple moth in Arizona-California and comments on its eradication. 27 pp.

Johnson, M.W.; Pickel, C.; Strand, L.L.; Varela, L.G.; Wilen, C.A.; Bolda, M.P.; Flint, M.L.; Frankie, Lam, W.K. and Zalom, F.G. 2007. Light brown apple moth in California: quarantine, management, and potential impacts. University of California Agriculture and Natural Resources. UC Statewide Integrated Pest Management Program. 21 pp.

McLennan, W. 1995. Value of agricultural commodities produced Australia 1993 – 94. Australian Bureau of Statistics. Catalogue No. 7503.0. 26 pp.

NAPIS. 2009. Map of light brown apple moth, *Epiphyas postvittana*: Pest Tracker. National Agricultural Pest Information System. http://pest.ceris.purdue.edu/searchmap.php?selectName=ITBUBPA

NAPPFAST. 2009. North Carolina State University Animal and Plant Health Inspection Service Plant Pest Forecasting System. www.nappfast.org

Palisade Corporation. 2002. A concise summary of @Risk probability distribution functions. Newfield, N.Y.

Palisade Corporation. 2002a. Newfield, N.Y.

Sutherst, R.W. 2000. Pests and pest management: impact of climate change. A report for the Rural Industries Research and Development Corporation. CSIRO Entomology. RIRDC Publication No 00/16. RIRDC Project No CSE-76A. 34 pp.

USDA-APHIS. 2007. LBAM situation report November 3, 2007. United States Department of Agriculture. Animal and Plant Health Inspection Service.

USDA-APHIS. 2007a. Federal domestic quarantine order: *Epiphyas postvittana* (Light Brown Apple Moth) (LBAM) DA-2007-42. United States Department of Agriculture. Animal and Plant Health Inspection Service. http://www.pestalert.org/OPRFiles/LBAM%20Federal%20Order%20Sept%2017%202007%20with%20Appendix.pdf

USDA-APHIS. 2009. Light brown apple moth. United States Department of Agriculture. Animal and Plant Health Inspection Service. http://www.aphis.usda.gov/plant_health/plant_pest_info/lba_moth/index.shtml

USDA-APHIS. 2009a. LBAM confirmations: 2007 to April, 22, 2009. United States Department of Agriculture. Animal and Plant Health Inspection Service. Data courtesy of Roxanne Broadway. USDA-APHIS-PPQ.

USDA-NASS. 2000. Noncitrus Fruits and Nuts 1999 Summary: Released July, 2000. National Agricultural Statistics Service (NASS). Agricultural Statistics Board. U.S. Department of Agriculture. 75 pp.

USDA-NASS. 2000a. Citrus Fruits 2000 Summary: Released September, 2000. National Agricultural Statistics Service (NASS). Agricultural Statistics Board. U.S. Department of Agriculture. 18 pp.

USDA-NASS. 2002. Noncitrus Fruits and Nuts 2001 Summary: Released July, 2002. National Agricultural Statistics Service (NASS). Agricultural Statistics Board. U.S. Department of Agriculture. 80 pp.

USDA-NASS. 2002a. Citrus Fruits 2002 Summary: Released September, 2002. National Agricultural Statistics Service (NASS). Agricultural Statistics Board. U.S. Department of Agriculture. 18 pp.

USDA-NASS. 2004. Citrus Fruits 2004 Summary: Released September, 2004. National Agricultural Statistics Service (NASS). Agricultural Statistics Board. U.S. Department of Agriculture. 49 pp.

USDA-NASS. 2005. Noncitrus Fruits and Nuts 2004 Summary: Released July, 2005. National Agricultural Statistics Service (NASS). Agricultural Statistics Board. U.S. Department of Agriculture. 80 pp.

USDA-NASS. 2006. Citrus Fruits 2006 Summary: Released September, 2006. National Agricultural Statistics Service (NASS). Agricultural Statistics Board. U.S. Department of Agriculture. 49 pp.

USDA-NASS. 2007. 2007 Census of agriculture. United States Department of Agriculture. National Agricultural Statistics Service. http://www.agcensus.usda.gov/Publications/2007/Online_Highlights/Desktop_Application/index.asp

USDA-NASS. 2008. Noncitrus Fruits and Nuts 2007 Summary: Released July, 2008. National Agricultural Statistics Service (NASS). Agricultural Statistics Board. U.S. Department of Agriculture. 79 pp.

USDA-NASS. 2008a. Citrus Fruits 2008 Summary: Released September, 2008. National Agricultural Statistics Service (NASS). Agricultural Statistics Board. U.S. Department of Agriculture. 49 pp.

Vose, D. 2000. Risk analysis: a quantitative guide. 2nd edition. John Wiley and Sons, Ltd. New York. 418 pp.

Wearing, C.H.; Thomas, W.P.; Dugdale, J.S. and Danthanarayana. W. 1991. Tortricid pests of pome and stone fruits, Australian and New Zealand species. *In*: van der Geest, L.P.S. and Evenhuis, H.H. (ed). Tortricid pests: their biology, natural enemies and control. World crop pests. Volume 5. Amsterdam, Netherlands: Elsevier. 453-472.

VII. Appendices

Appendix 1. 2007 apple crop summary data for areas at risk for LBAM (USDA-NASS, 2007, 2008).

State[1]	At-Risk Bearing Acreage	State Bearing Acreage	Proportion	Value (1,000s)	At-Risk Value (1,000s)[2]
Alabama	307	307	1.00	NR	2,179
Arizona	1,249	1,249	1.00	5,040	5,040
Arkansas	220	220	1.00	NR	1,562
California	20,954	20,954	1.00	90,769	90,769
Colorado	0	1,719	0	2,790	0
Connecticut	455	2,191	0.21	10,766	2,236
Delaware	NR	NR	NC	NR	NC
Florida	40	40	1.00	NR	284
Georgia	601	601	1.00	1,000	1,000
Illinois	364	1,979	0.18	3,703	681
Indiana	168	1,839	0.09	9,679	884
Kansas	17	245	0.07	1,739	121
Kentucky	964	964	1.00	207	207
Louisiana	29	29	1.00	NR	206
Maryland	2,064	2,064	1.00	6,009	6,009
Mississippi	100	100	1.00	NR	710
Missouri	133	1,819	0.07	604	44
Nevada	4	94	0.04	NR	28
New Jersey	1,287	1,859	0.69	9,609	6,652
New Mexico	724	1,769	0.41	NR	5,139
New York	1,526	44,916	0.03	285,855	9,712
North Carolina	6,803	6,803	1.00	5,864	5,864
Ohio	1,313	5,296	0.25	24,159	5,990
Oklahoma	92	92	1.00	NR	653
Oregon	4,833	5,562	0.87	37,943	32,970
Pennsylvania	17,946	20,791	0.86	66,489	57,391
South Carolina	482	482	1.00	142	142
Tennessee	1,062	1,062	1.00	40	40
Texas	278	278	1.00	NR	1,973
Utah	59	1,416	0.04	5,916	247
Virginia	12,619	12,619	1.00	27,375	27,375
Washington	106,591	152,334	0.70	1,745,620	1,221,444
West Virginia	4,424	4,424	1.00	7,406	7,406
Total					1,494,956
				US Value (1,000s)	2,579,714
				US Bearing Acreage	363,440

[1]Red text indicates that all counties in the state were considered at-risk for LBAM establishment.
[2]Blue text indicates that the at-risk crop value was estimated based on the state's at-risk bearing acreage and the ratio of U.S. bearing acreage to U.S. crop value (USDA-NASS, 2007, 2008).
NR indicates data was not reported (USDA-NASS, 2007, 2008).
NC indicates the values were not calculated due to a lack of data.

Appendix 2. 2007 grape crop summary data for areas at risk for LBAM (USDA-NASS, 2007, 2008).

State[1]	At-Risk Bearing Acreage	State Bearing Acreage	Proportion	Value (1,000s)	At-Risk Value (1,000s)[2]
Alabama	345	345	1.000	NR	1,276
Arizona	229	229	1.000	NR	847
Arkansas	680	680	1.000	NR	2,515
California	809,281	809,281	1.000	3,077,769	3,077,769
Colorado	0	805	0.000	NR	0
Connecticut	43	399	0.108	NR	159
Delaware	NR	NR	NC	NR	NC
Florida	767	767	1.000	NR	2,836
Georgia	1,226	1,226	1.000	3,477	3,477
Illinois	180	754	0.239	NR	666
Indiana	21	402	0.052	NR	78
Kansas	72	210	0.343	NR	266
Kentucky	407	407	1.000	NR	1,505
Louisiana	71	71	1.000	NR	263
Maryland	372	372	1.000	NR	1,376
Mississippi	570	570	1.000	NR	2,108
Missouri	646	1,342	0.481	2,331	1,122
Nevada	2	38	0.053	NR	7
New Jersey	663	878	0.755	NR	2,452
New Mexico	655	930	0.704	NR	2,422
New York	2,504	40,675	0.062	49,222	3,030
North Carolina	2,100	2,100	1.000	4,040	4,040
Ohio	72	1,554	0.046	2,985	138
Oklahoma	327	327	1.000	NR	1,209
Oregon	14,430	14,754	0.978	72,568	70,974
Pennsylvania	768	13,570	0.057	20,913	1,184
South Carolina	387	387	1.000	NR	1,431
Tennessee	367	367	1.000	NR	1,357
Texas	2,961	2,961	1.000	4,751	4,751
Utah	4	46	0.087	NR	15
Virginia	2,661	2,661	1.000	7,560	7,560
Washington	53,448	57,025	0.937	172203	161,401
West Virginia	167	167	1.000	NR	618
Total					3,358,851
				US Value (1,000s)	3,447,034
				US Bearing Acreage	932,150

[1]Red text indicates that all counties in the state were considered at-risk for LBAM establishment.
[2]Blue text indicates that the at-risk crop value was estimated based on the state's at-risk bearing acreage and the ratio of U.S. bearing acreage to U.S. crop value (USDA-NASS, 2007, 2008).
NR indicates data was not reported (USDA-NASS, 2007, 2008).
NC indicates the values were not calculated due to a lack of data.

Appendix 3. 2007 orange crop summary data for areas at risk for LBAM (USDA-NASS, 2007, 2008a).

State[1]	State Bearing Acreage
Alabama	6
Arizona	2,526
California	200,424
Florida	530,535
Louisiana	376
Texas	8,511
US Value (1,000s)	2,216,471

[1]Red text indicates that all counties in the state were considered at-risk for LBAM establishment.

Appendix 4. 2007 pear crop summary data for areas at risk for LBAM (USDA-NASS, 2007, 2008).

State[1]	At-Risk Bearing Acreage	State Bearing Acreage	Proportion	Value (1,000s)	At-Risk Value (1,000s)[2]
Alabama	87	87	1.000	NR	531
Arizona	13	40	0.325	NR	79
Arkansas	50	50	1.000	NR	305
California	14,818	14,818	1.000	83,031	83,031
Colorado	0	294	0.000	2,636	0
Connecticut	2	167	0.012	2,600	31
Delaware	NC	NR	NC	NR	NC
Florida	94	94	1.000	NR	573
Georgia	383	383	1.000	NR	2,336
Illinois	1	48	0.021	NR	6
Indiana	10	38	0.263	NR	61
Kansas	1	NR	NC	NR	6
Kentucky	79	79	1.000	NR	482
Louisiana	20	20	1.000	NR	122
Maryland	101	101	1.000	NR	616
Mississippi	48	48	1.000	NR	293
Missouri	18	61	0.295	NR	110
Nevada	1	NR	NC	NR	6
New Jersey	98	293	0.334	NR	598
New Mexico	55	109	0.505	NR	335
New York	28	1,322	0.021	5,617	119
North Carolina	47	47	1.000	NR	287
Ohio	17	127	0.134	NR	104
Oklahoma	184	184	1.000	NR	1,122
Oregon	16,590	17,341	0.957	89,851	85,960
Pennsylvania	262	855	0.306	3,586	1,099
South Carolina	67	67	1.000	NR	409
Tennessee	56	56	1.000	NR	342
Texas	398	398	1.000	NR	2,428
Utah	10	125	0.080	950	76
Virginia	127	127	1.000	NR	775
Washington	11,036	23,924	0.461	178,667	82,418
West Virginia	107	107	1.000	653	653
Total					265,311
				US Value (1,000s)	363,092
				US Bearing Acreage	59,530

[1]Red text indicates that all counties in the state were considered at-risk for LBAM establishment.
[2]Blue text indicates that the at-risk crop value was estimated based on the state's at-risk bearing acreage and the ratio of U.S. bearing acreage to U.S. crop value (USDA-NASS, 2007, 2008).
NR indicates data was not reported (USDA-NASS, 2007, 2008).
NC indicates the values were not calculated due to a lack of data.

Appendix 5. Crop data for 1998 to 2007 (USDA-NASS, 2000, 2000a, 2002, 2002a, 2004, 2005, 2006, 2008, 2008a).

Year	Apple Value (1,000s)	Apple Value Adjusted to 2007 Dollars (1,000s)	At-Risk Apple Value (1,000s)
1998	1,316,172	1,667,667	966,421
1999	1,563,582	1,929,065	1,117,902
2000	1,325,641	1,581,727	916,618
2001	1,477,164	1,734,765	1,005,304
2002	1,581,260	1,813,491	1,050,926
2003	1,817,240	2,045,268	1,185,242
2004	1,629,071	1,774,915	1,028,571
2005	1,675,097	1,765,050	1,022,855
2006	2,236,112	2,298,723	1,332,121
2007	2,579,714	2,579,714	1,494,956
MIN			916,618
ML			1,112,092
MAX			1,494,956
Proportion of US value			0.580

Year	Grape Value (1,000s)	Grape Value Adjusted to 2007 Dollars (1,000s)	At-Risk Grape Value (1,000s)
1998	2,644,035	3,350,147	3,264,443
1999	2,926,910	3,611,067	3,518,688
2000	3,096,436	3,694,603	3,600,087
2001	2,921,299	3,430,741	3,342,975
2002	2,841,569	3,258,894	3,175,524
2003	2,626,846	2,956,463	2,880,830
2004	3,013,410	3,283,188	3,199,197
2005	3,494,095	3,681,728	3,587,541
2006	3,303,668	3,396,171	3,309,289
2007	3,447,034	3,447,034	3,358,851
MIN			2,880,830
ML			3,323,742
MAX			3,600,087
Proportion of US value			0.974

Year	Orange Value (1,000s)	Orange Value Adjusted to 2007 Dollars (1,000s)
1998	1,965,358	2,490,224
1999	1,700,532	2,098,027
2000	1,666,100	1,987,956
2001	1,682,790	1,976,250
2002	1,846,199	2,117,340
2003	1,564,658	1,760,992
2004	1,774,453	1,933,312
2005	1,475,381	1,554,609
2006	1,829,860	1,881,096
2007	2,216,471	2,216,471
MIN		1,554,609
ML		2,001,628
MAX		2,490,224
Proportion of US value		1.000

Year	Pear Value (1,000s)	Pear Value Adjusted to 2007 Dollars (1,000s)	At-Risk Pear Value (1,000s)
1998	281,611	356,818	260,726
1999	298,009	367,668	268,654
2000	250,273	298,621	218,202
2001	272,727	320,288	234,034
2002	264,334	293,144	214,200
2003	273,142	307,416	224,628
2004	301,188	328,152	239,780
2005	293,863	309,643	226,255
2006	329,928	339,166	247,828
2007	363,092	363,092	265,311
MIN			214,200
ML			239,962
MAX			268,654
Proportion of US value			0.731

Appendix 6. LBAM crop data for five affected Australian States for the 1993/1994 production year (McLennan, 1995; Sutherst, 2000).

State	LBAM Grape Value	Total Grape Value	Grape Proportion	LBAM Orange Value	Total Orange Value	Orange Proportion
NSW	488,000	74,800,000	0.007	1,072,000	79,000,000	0.014
Vic	1,629,000	114,900,000	0.014	1,845,000	51,000,000	0.036
SA	2,269,000	148,000,000	0.015	3,025,000	83,600,000	0.036
Tas	18,000	1,700,000	0.011	na	na	na
WA	17,000	17,000,000	0.001	18,000	2,700,000	0.007
Min	17,000	1,700,000	0.001	18,000	2,700,000	0.007
ML	884,200	71,280,000	0.010	1,490,000	54,075,000	0.023
Max	2,269,000	148,000,000	0.015	3,025,000	83,600,000	0.036

State	LBAM Apple Value	Total Apple Value	Apple Proportion	LBAM Pear Value	Total Pear Value	Pear Proportion
NSW	634,000	38,800,000	0.016	46,000	1,700,000	0.027
Vic	2,236,000	91,300,000	0.024	2,081,000	74,200,000	0.028
SA	1,025,000	25,800,000	0.040	191,000	5,500,000	0.035
Tas	600,000	33,200,000	0.018	9,000	700,000	0.013
WA	87,000	32,100,000	0.003	20,000	5,900,000	0.003
Min	87,000	25,800,000	0.003	9,000	700,000	0.003
ML	916,400	44,240,000	0.020	469,400	17,600,000	0.021
Max	2,236,000	91,300,000	0.040	2,081,000	74,200,000	0.035

State	LBAM Total Damage Value	Total Value	Total Proportion
NSW	2,240,000	194,300,000	0.012
Vic	7,791,000	331,400,000	0.024
SA	6,510,000	262,900,000	0.025
Tas	627,000	35,600,000	0.018
WA	142,000	57,700,000	0.002
Min	142,000	35,600,000	0.002
ML	3,462,000	176,380,000	0.016
Max	7,791,000	331,400,000	0.025

Appendix 7. Quarantine and research proportions of grower costs (Sutherst, 2000).

Item	Value	Proporiton	Proportion relative to grower cost
grower cost	18.7	0.886255924	1.000
quarantines	1.5	0.071090047	0.080
research	0.9	0.042654028	0.048
total	21.1	1	

Appendix 8. Model for estimating LBAM annual economic costs to apples, grapes, oranges and pears if introduced into at-risk areas in the conterminous United States. Most likely values are reported in each cell. Color codes: yellow = parameter, green = probabilistic function, fuschia = output.

	A	B	C	D	E	F
1	**Step**	**Value**	**Parameters**			
2	Commercial apple production value in LBAM at-risk areas	1,143,323,529	min/ml/max	916,618,143	1,112,091,696	1,494,956,244
3	Proportion of apple crop damaged by LBAM	0.021	min/ml/max	0.003	0.020	0.040
4	LBAM apple crop damage value in LBAM at-risk areas	23,438,132				
5						
6	Commercial grape production value in LBAM at-risk areas	3,295,981,074	min/ml/max	2,880,829,971	3,323,742,419	3,600,086,795
7	Proportion of grape crop damaged by LBAM	0.009	min/ml/max	0.001	0.01	0.015
8	LBAM grape crop damage value in LBAM at-risk areas	30,762,490				
9						
10	Commercial orange production value in LBAM at-risk areas	2,008,557,300	min/ml/max	1,554,609,000	2,001,627,700	2,490,224,000
11	Proportion of orange crop damaged by LBAM	0.023	min/ml/max	0.007	0.023	0.036
12	LBAM orange crop damage value in LBAM at-risk areas	45,192,539				
13						
14	Commercial pear production value in LBAM at-risk areas	240,450,153	min/ml/max	214,199,688	239,961,754	268,654,213
15	Proportion of pear crop damaged by LBAM	0.020	min/ml/max	0.003	0.021	0.035
16	LBAM pear crop damage value in LBAM at-risk areas	4,889,153				
17						
18	Total crop damage in LBAM at-risk areas	104,282,315				
19						
20	Relative quarantine cost proportion	0.080	min/ml/max	0.010	0.080	0.150
21	Quarantine costs	8,342,585				
22						
23	Relative research cost proportion	0.049	min/ml/max	0.000	0.048	0.103
24	Research Costs	5,127,214				
25						
26	Total costs from LBAM crop damage, quarantines and research	117,752,114				

Appendix 9. Model formula table for estimating LBAM annual economic costs to apples, grapes, oranges and pears if introduced into at-risk areas in the conterminous United States.

	A	B	C	D	E	F
1	**Step**	**Value**	**Parameters**			
2	Commercial apple production value in LBAM at-risk areas	=RiskPert(D2,E2,F2)	min/ml/max	916,618,143	1,112,091,696	1,494,956,244
3	Proportion of apple crop damaged by LBAM	=RiskPert(D3,E3,F3)	min/ml/max	0.003	0.020	0.040
4	LBAM apple crop damage value in LBAM at-risk areas	=RiskOutput("LBAM apple economic damage")+B2*B3				
5						
6	Commercial grape production value in LBAM at-risk areas	=RiskPert(D6,E6,F6)	min/ml/max	2,880,829,971	3,323,742,419	3,600,086,795
7	Proportion of grape crop damaged by LBAM	=RiskPert(D7,E7,F7)	min/ml/max	0.001	0.01	0.015
8	LBAM grape crop damage value in LBAM at-risk areas	=RiskOutput("LBAM grape economic damage")+B6*B7				
9						
10	Commercial orange production value in LBAM at-risk areas	=RiskPert(D10,E10,F10)	min/ml/max	1,554,609,000	2,001,627,700	2,490,224,000
11	Proportion of orange crop damaged by LBAM	=RiskPert(D11,E11,F11)	min/ml/max	0.007	0.023	0.036
12	LBAM orange crop damage value in LBAM at-risk areas	=RiskOutput("LBAM orange economic damage")+B10*B11				
13						
14	Commercial pear production value in LBAM at-risk areas	=RiskPert(D14,E14,F14)	min/ml/max	214,199,688	239,961,754	268,654,213
15	Proportion of pear crop damaged by LBAM	=RiskPert(D15,E15,F15)	min/ml/max	0.003	0.021	0.035
16	LBAM pear crop damage value in LBAM at-risk areas	=RiskOutput("LBAM pear economic damage")+B14*B15				
17						
18	Total crop damage in LBAM at-risk areas	=RiskOutput("total crop damage in LBAM at-risk areas")+B4+B8+B12+B16				
19						
20	Relative quarantine cost proportion	=RiskPert(D20,E20,F20)	min/ml/max	0.010	0.080	0.150
21	Quarantine costs	=RiskOutput("quarantine costs")+B18*B20				
22						
23	Relative research cost proportion	=RiskPert(D23,E23,F23)	min/ml/max	0.000	0.048	0.103
24	Research Costs	=RiskOutput("research costs")+B18*B23				
25						
26	Total costs from LBAM crop damage, quarantines and research	=RiskOutput("total LBAM costs")+B18+B21+B24				

Appendix 10. Model for calculating the quarantine proportion confidence intervals (Caton pers. comm., 2007; Cochran, 1977).

	A	B	C	D	E	F
1	Quarantine proportion	Calculation				
2	proportion	0.08000	numerator	8	denominator	100
3	st. dev. prop	0.02713	*n*	100		
4						
5	95%					
6	z	1.96				
7	lower	0.02683	<==Note: if lower limit less than 0, it indicates the proportion is not significantly different from zero at this *P*			
8	upper	0.13317				
9						
10	99%					
11	z	2.58				
12	lower	0.01001				
13	upper	0.14999				

Appendix 11. Model formula table for calculating the quarantine proportion confidence intervals (Caton pers. comm., 2007; Cochran, 1977).

	A	B	C	D	E	F
1	Quarantine proportion	Calculation				
2	proportion	=D2/F2	numerator	8	denominator	100
3	st. dev. prop	=SQRT(((B2*(1-B2))/D3))	*n*	100		
4						
5	95%					
6	z	1.96				
7	lower	=B2-(B6*B3)	<==Note: if lower limit less than 0, it indicates the proportion is not significantly different from zero at this *P*			
8	upper	=B2+(B6*B3)				
9						
10	99%					
11	z	2.58				
12	lower	=B2-(B11*B3)				
13	upper	=B2+(B11*B3)				

Appendix 12. Model for calculating the research proportion confidence intervals (Caton pers. comm., 2007; Cochran, 1977).

	A	B	C	D	E	F
1	Research proportion	Calculation				
2	proportion	0.04800	numerator	4.8	denominator	100
3	st. dev. prop	0.02138	*n*	100		
4						
5	95%					
6	z	1.96				
7	lower	0.00610	<==Note: if lower limit less than 0, it indicates the proportion is not significantly different from zero at this *P*			
8	upper	0.08990				
9						
10	99%					
11	z	2.58				
12	lower	-0.00715				
13	upper	0.10315				

Appendix 13. Model formula table for calculating the research proportion confidence intervals (Caton pers. comm., 2007; Cochran, 1977).

	A	B	C	D	E	F
1	Research proportion	Calculation				
2	proportion	=D2/F2	numerator	4.8	denominator	100
3	st. dev. prop	=SQRT(((B2*(1-B2))/D3))	*n*	100		
4						
5	95%					
6	z	1.96				
7	lower	=B2-(B6*B3)	<==Note: if lower limit less than 0, it indicates the proportion is not significantly different from zero at this *P*			
8	upper	=B2+(B6*B3)				
9						
10	99%					
11	z	2.58				
12	lower	=B2-(B11*B3)				
13	upper	=B2+(B11*B3)				