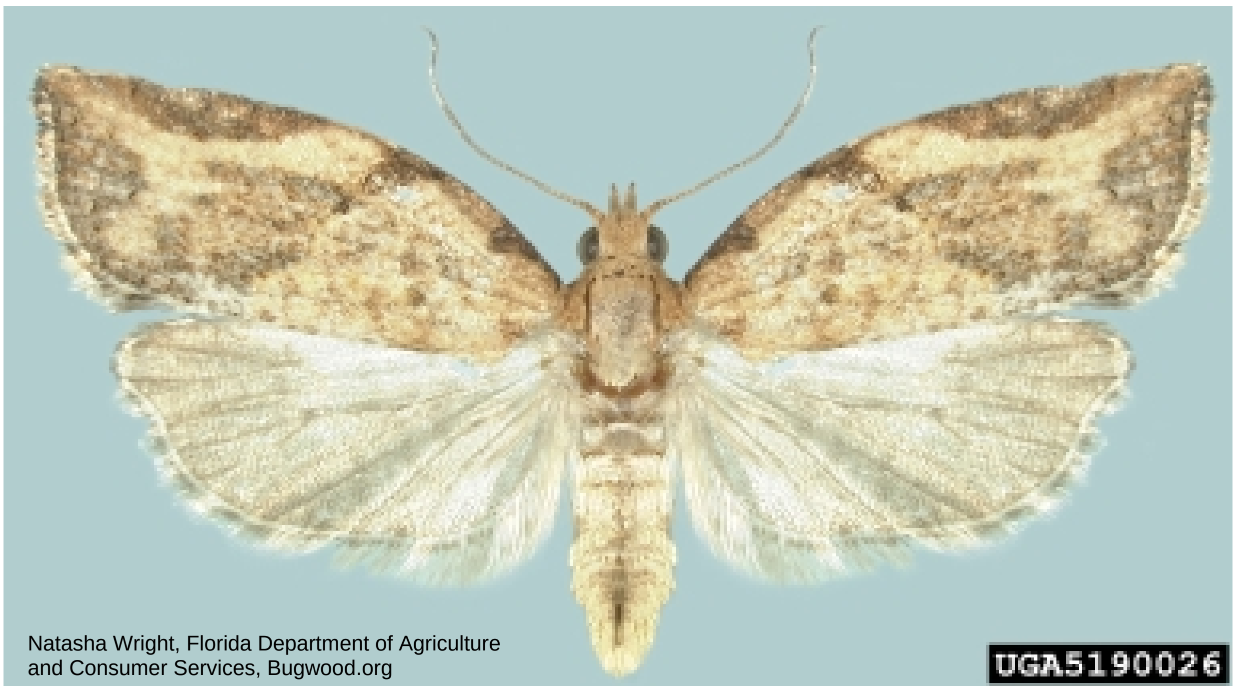
United States Department of Agriculture
Animal and Plant Health Inspection Service

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

November 2007



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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 introduction based on climate and host 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 \$105 million. The 5^{th} and 95^{th} percentile values were: \$77 million and \$134 million, i.e. 95 percent of the time, total annual costs exceeded \$77 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.

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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).

On February 7, 2006, an LBAM detection was confirmed in Berkeley, California (USDA-APHIS, 2007). Trapping evidence indicated that LBAM may have been present in California since 2006. The LBAM detection resulted in the implementation of a joint emergency response by the USDA, CDFA and affected counties. As of November 3, 2007, LBAM has been detected in 12 California counties (USDA-APHIS, 2007a) (Figure 1).

LBAM's detection in California has resulted in surveys, quarantines and aerial control programs at the costs of tens of millions of dollars. 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.

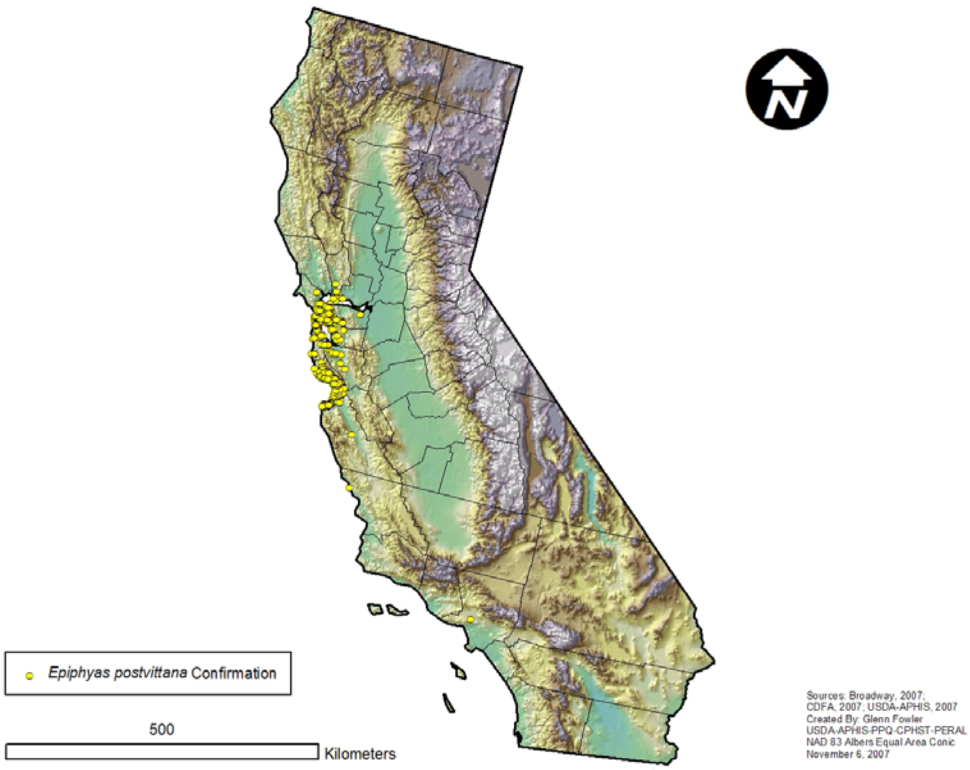

Figure 1. LBAM detections as of November 3, 2007.

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, 2005, 2005a).

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 introduction 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 (≥ 1,926 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 (2007) system and ten year historical daily climatology (1997 to 2006) at a 10 km^2 resolution.

We masked areas below USDA Plant Hardiness Zone 6 as being too cold for LBAM permanent establishment using the NAPPFAST (2007) climate match tool (USDA-ARS, 1990) (Figure 2). This establishment threshold estimate was based on LBAM's global distribution in relation to the USDA Plant Hardiness Zones (Borchert pers. comm., 2007; CABI, 2006; USDA-ARS, 1990).

We geospatially visualized counties that intersected the climate match area for LBAM establishment with ArcGIS 9.2 (ESRI, 2007) (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 total apple, grape, orange and pear crop acreage data for 2002 and the crop acreage per county was geospatially visualized (USDA-NASS, 2002) (Figures 4 to 7).

We summed each crop's acreage in at-risk counties for each affected State and divided this value by the total State acreage for each crop (USDA-NASS, 2002). This proportion was multiplied times the total value of each crop (2004 data for apples, grapes and pears and 2005 data for oranges) to estimate the economic value of each crop in the at-risk counties (USDA-NASS, 2005, 2005a) (Appendix 1).

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 5 and 6). 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 used the total estimated 2002 annual crop values for each crop in the at-risk counties from the geospatial analysis as the most likely value in the PERT distribution for each crop (Table 1). To account for variation in annual production, we assumed a normal distribution and calculated the mean and standard deviation in U.S. production (thousands of hectares) for each crop from 1996 to 2005 (FAOSTAT, 2007) (Appendix 4). We calculated the proportion of the mean that the standard deviation comprised and then the proportion value at three standard deviations. The most likely value for each crop was then adjusted by ± the product of itself and the proportion at three standard deviations to generate the minimum and maximum values in the PERT distribution (Table 1). This range captures 99.73 percent of each crops estimated annual value distribution (Vose, 2000).

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 2). 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 3, 7 and 8).

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 3, 9 and 10).

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 (based on 2002 estimated crop values)	Apples	985,177,216	1,338,556,000	1,691,934,784
		Grapes	2,267,873,034	2,745,609,000	3,223,344,966
		Oranges	1,370,093,120	1,556,924,000	1,743,754,880
		Pears	228,545,040	249,776,000	271,006,960
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 (85%), grapes (97%), oranges (100%) and pears (94%) (Appendix 1).

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 5^{th}, mean and 95^{th} percentile values were: $68,641,000; $93,173,000 and $118,458,000. The crops listed in descending order or economic loss and percentage of total crop damage costs were: oranges (38%), apples (29%), grapes (28%) and pears (5%). The 5^{th}, mean and 95^{th} percentile values for the total annual estimated costs with the addition of quarantines and research were: $77,092,000; $105,210,000 and $134,448,000 (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).

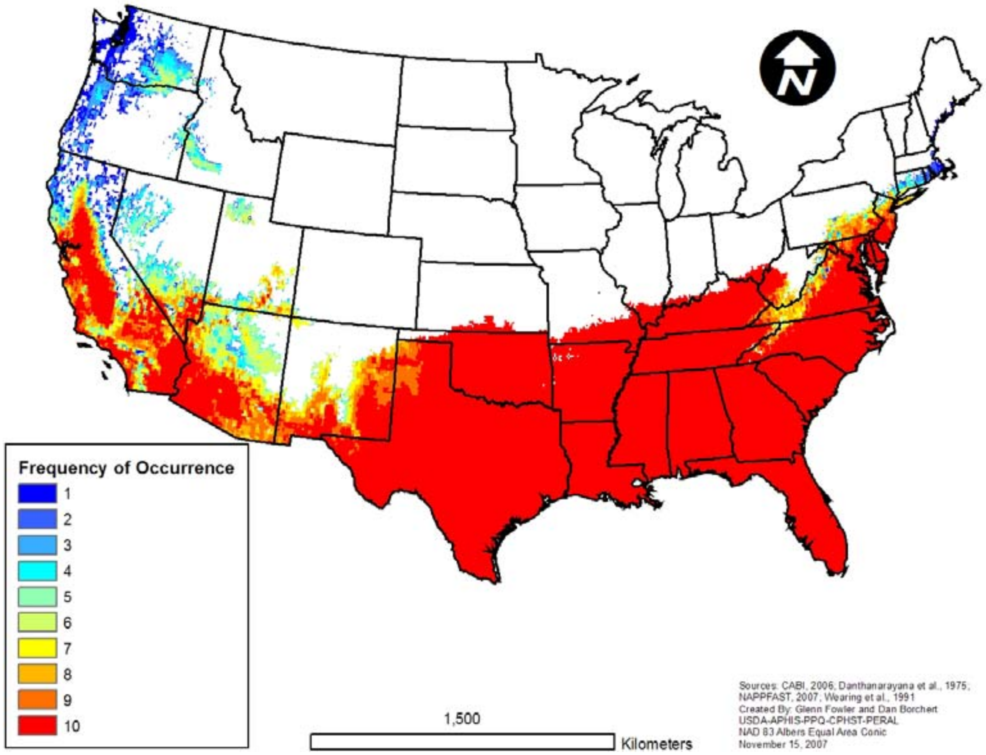

Figure 2. Climate match analysis for areas conducive to LBAM establishment. The results are reported in terms of frequency of years from 1997 to 2006 where enough degree days occurred for LBAM to complete three or more generations.

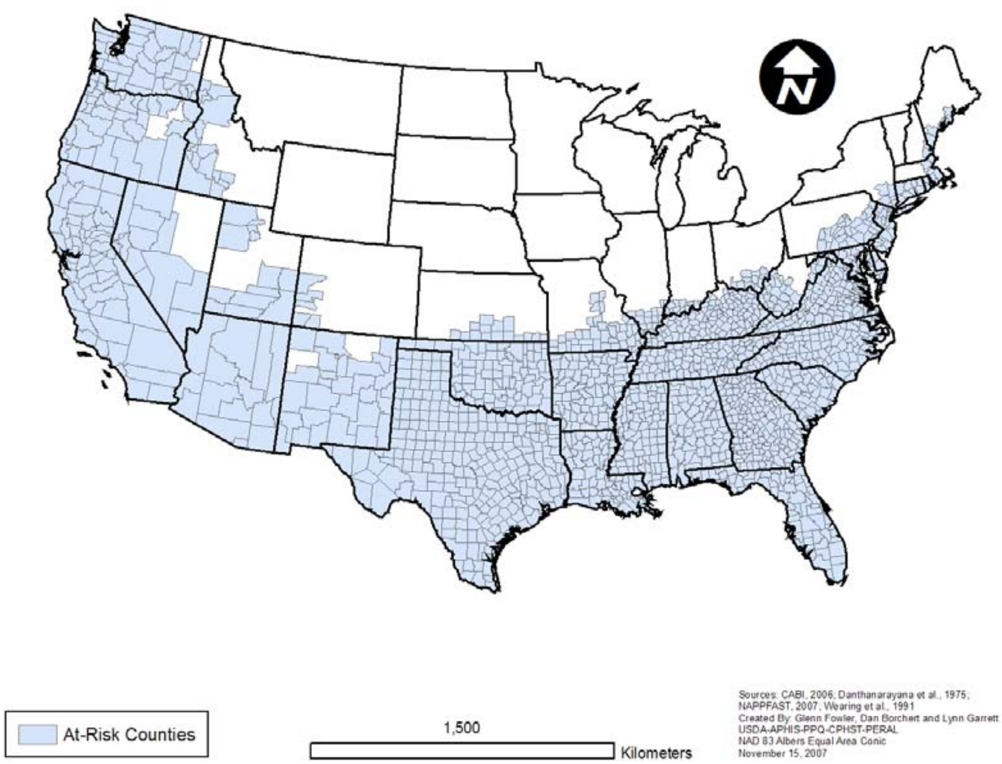

Figure 3. Counties at risk for LBAM introduction based on climate match.

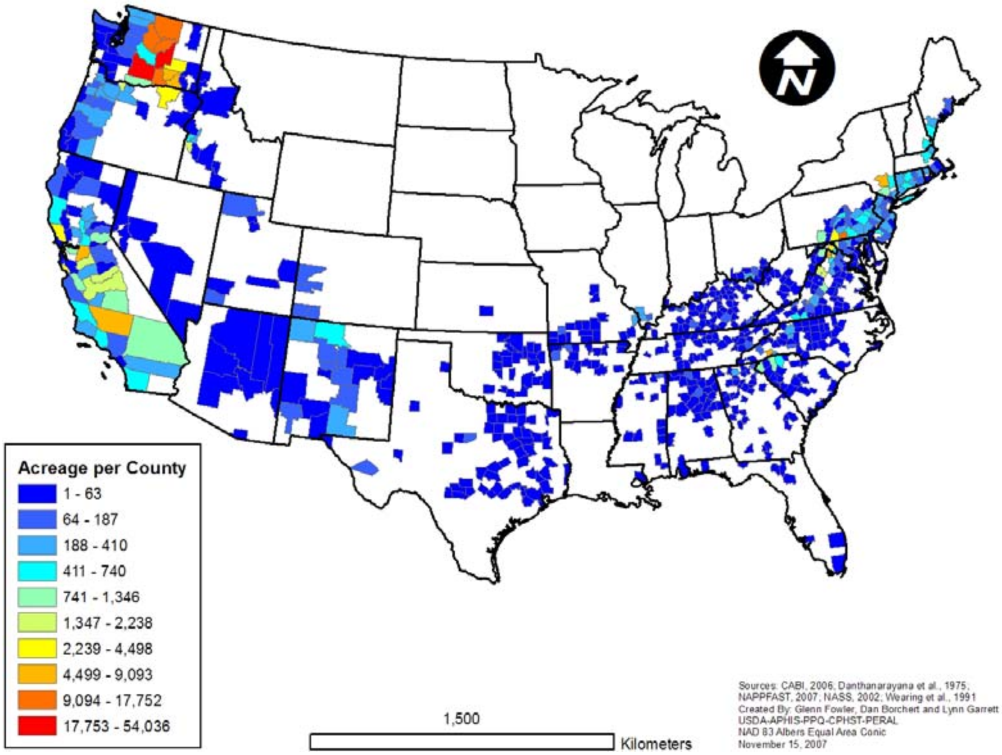

Figure 4. Apple acreage in counties at risk for LBAM introduction.

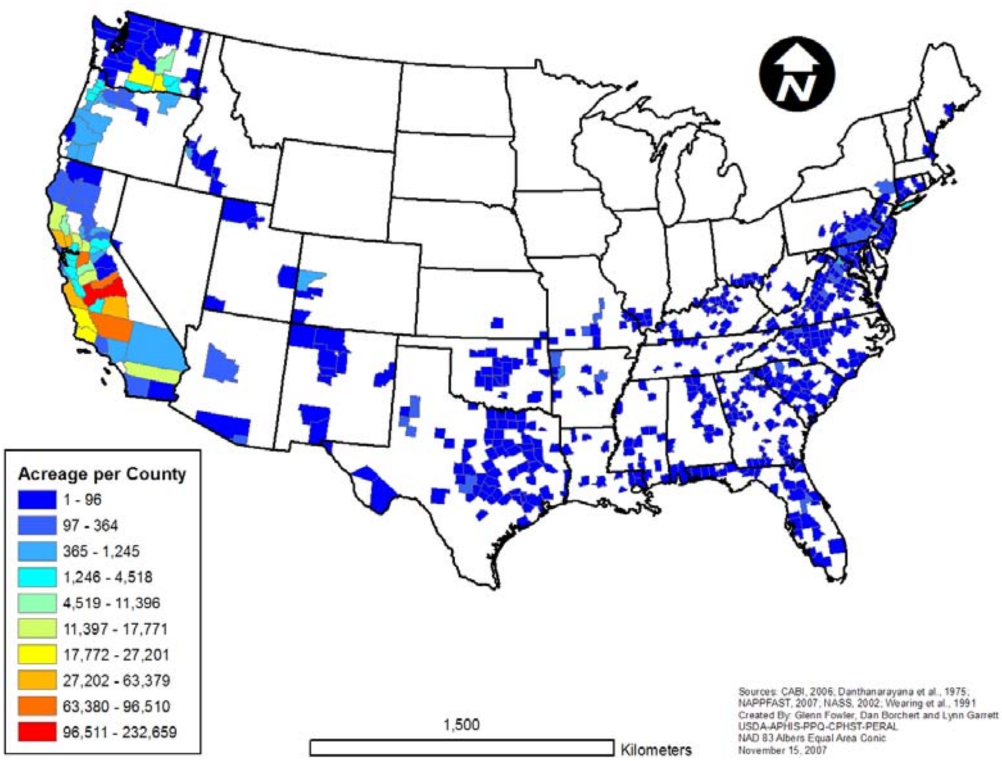

Figure 5. Grape acreage in counties at risk for LBAM introduction.

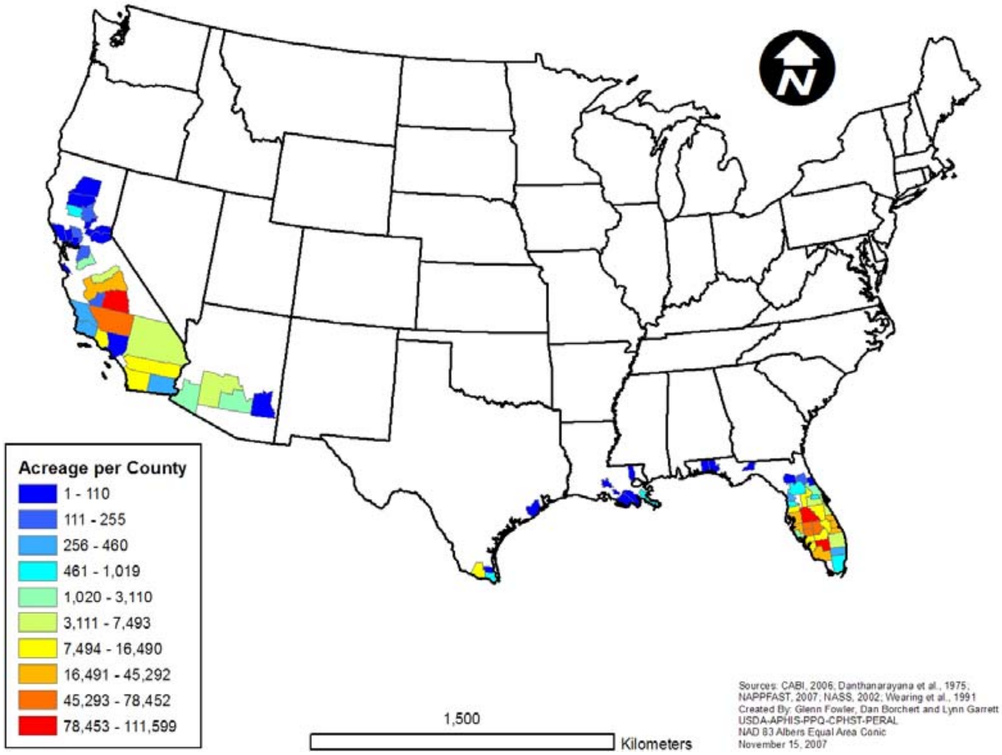

Figure 6. Orange acreage in counties at risk for LBAM introduction.

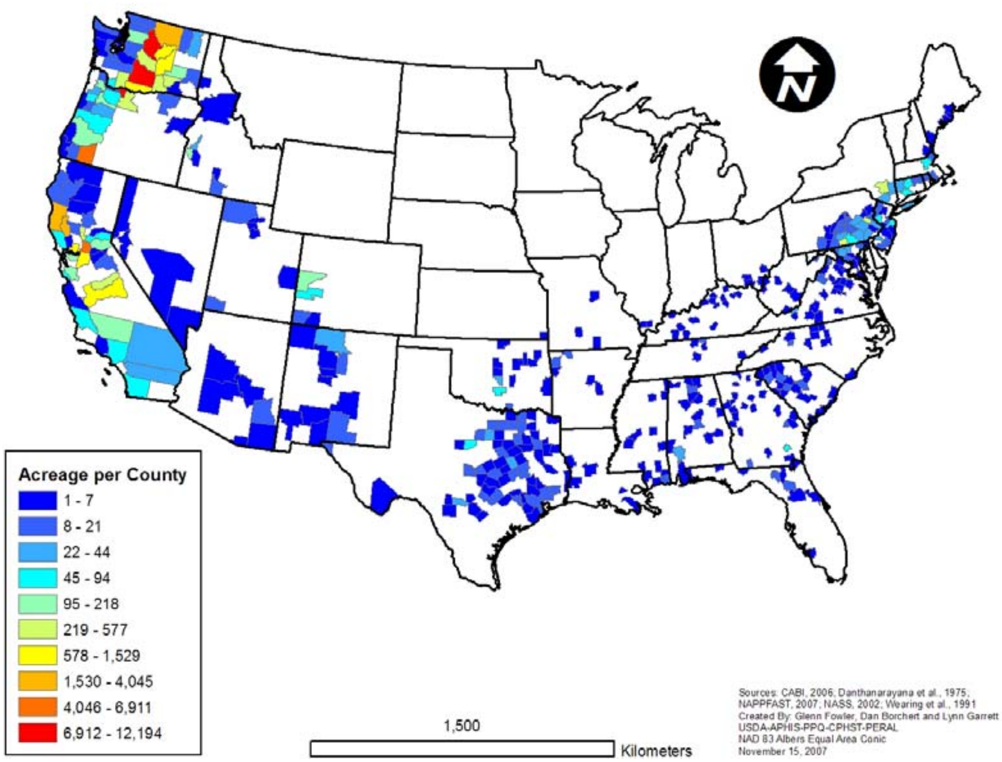

Figure 7. Pear acreage in counties at risk for LBAM introduction.

Table 2. Model outputs for estimated LBAM annual economic costs if introduced into counties at risk for introduction. 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	12,041,000	27,439,000	44,301,000
Grape	13,060,000	25,623,000	37,146,000
Orange	20,656.000	35,031,000	49,028,000
Pear	2,534,000	5,080,000	7,485,000
Total Crop Costs	68,641,000	93,173,000	118,458,000
Quarantine Costs	3,186,000	7,454,000	12,353,000
Research Costs	1,575,000	4,583,000	8,027,000
Total Costs	77,092,000	105,210,000	134,448,000

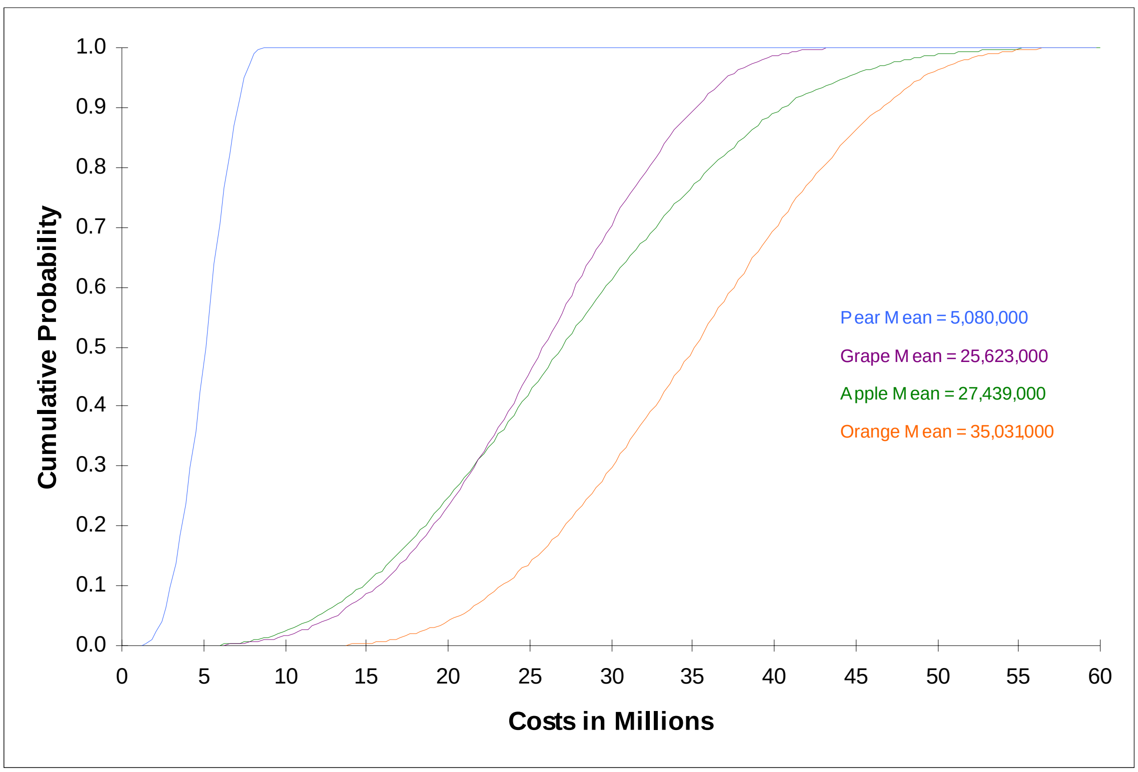

Figure 8. Cumulative distribution functions for estimated annual costs to apples, grapes, oranges and pears if LBAM were introduced into at-risk areas.

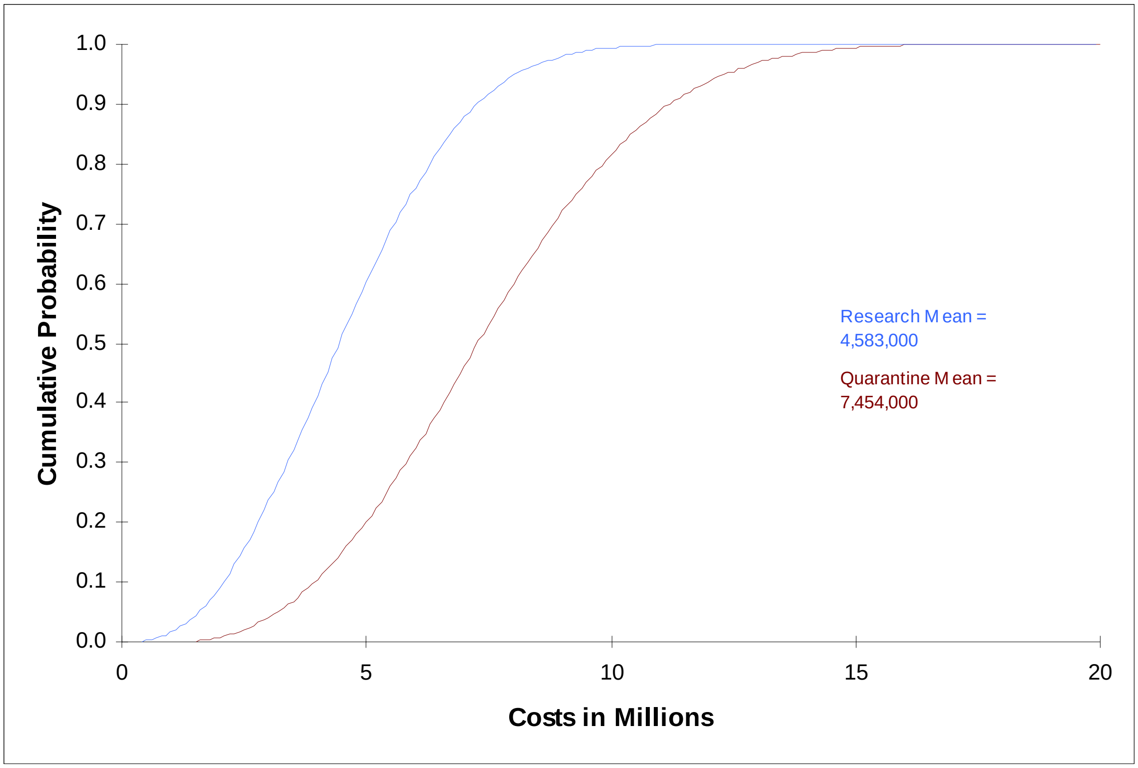

Figure 9. Cumulative distribution functions for estimated annual quarantine and research costs if LBAM were introduced into at-risk areas.

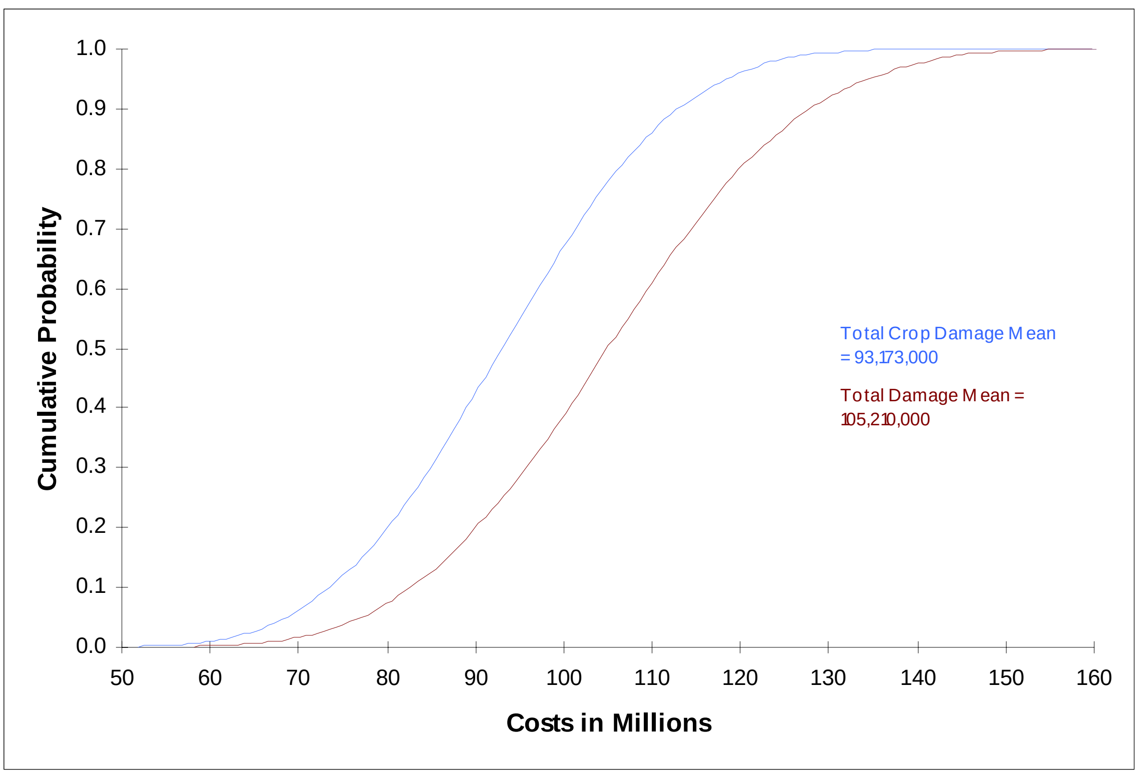

Figure 10. Cumulative distribution functions for estimated total annual crop damage and total annual costs if LBAM were introduced into at-risk areas.

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V. Appendices

Appendix 1. Summary crop data for areas at risk for LBAM introduction.

Light Brown Apple Moth (LBAM)
Estimated State, Region and National Economic Impact Estimates for Selected Major Host Commodities
for Counties in States Having Climatic Conditions Sufficient to Support LBAM Life Cycle $1,000

Region		Apple	Grape	Pears	Oranges	Total
East	Alabama	N/R	N/R	N/R	N/R	$0
	Connecticut	$47,420	N/R	$348	N/R	$47,768
	Delaware	N/R	N/R	N/R	N/R	$0
	Florida	N/R	N/R	N/R	$1,089,751	$1,089,751
	Georgia	$1,228	$1,135	N/R	N/R	$2,363
	Kentucky	$997	N/R	N/R	N/R	$997
	Maine	$3,952	N/R	N/R	N/R	$3,952
	Maryland	$4,424	N/R	N/R	N/R	$4,424
	Massachusetts	$2,914	N/R	N/R	N/R	$2,914
	Mississippi	N/R	N/R	N/R	N/R	$0
	New Hampshire	$1,527	N/R	N/R	N/R	$1,527
	New Jersey	$5,440	N/R	N/R	N/R	$5,440
	New York	$18,372	$3,502	$957	N/R	$22,831
	North Carolina	$21,303	$2,187	N/R	N/R	$23,490
	Ohio	$1,169	$73	N/R	N/R	$1,242
	Pennsylvania	$30,777	$1,243	$1,404	N/R	$33,424
	Rhode Island	$785	N/R	N/R	N/R	$785
	South Carolina	$909	N/R	N/R	N/R	$909
	Tennessee	$880	N/R	N/R	N/R	$880
	Virginia	$20,963	$4,477	N/R	N/R	$25,441
	West Virginia	$6,980	N/R	N/R	N/R	$6,980
Central	Arkansas	$443	$3,498	N/R	N/R	$3,940
	Illinois	$2,057	N/R	N/R	N/R	$2,057
	Indiana	$137	N/R	N/R	N/R	$137
	Kansas	$44	N/R	N/R	N/R	$44
	Louisiana	N/R	N/R	N/R	N/R	$0
	Missouri	$1,147	$678	N/R	N/R	$1,825
	Oklahoma	N/R	N/R	N/R	N/R	$0
	Texas	N/R	$2,280	N/R	$1,567	$3,848
West	Arizona	$607	$1,692	N/R	$2,185	$4,484
	California	$93,367	$2,559,303	$67,166	$463,420	$3,183,256
	Colorado	$8,744	N/R	$720	N/R	$9,463
	Idaho	$14,470	N/R	N/R	N/R	$14,470
	Nevada	N/R	N/R	N/R	N/R	$0
	New Mexico	$543	N/R	N/R	N/R	$543
	Oregon	$27,628	$31,485	$62,946	N/R	$122,059
	Utah	$279	N/R	$54	N/R	$334
	Washington	$1,019,051	$134,056	$116,181	N/R	$1,269,289
Crop Value at Risk from LBAM - National Total		**$1,338,556**	**$2,745,609**	**$249,776**	**$1,556,924**	**$5,890,866**
	East Regional Total	$170,040	$12,617	$2,709	$1,089,751	$1,275,117
	Central Regional Total	$3,827	$6,456	$0	$1,567	$11,850
	West Regional Total	$1,164,689	$2,726,536	$247,068	$465,605	$4,603,898
Total U.S. Reported Commercial Crop Value for Utilized Production USDA - NASS		$1,581,260	$2,841,569	$264,334	$1,564,658	$6,251,821
Percent of National Aggregated Crop Value at Risk		85%	97%	94%	100%	94%
Estimate of LBAM Annual Grower Costs When Based on Gross Value of Selected Hosts (Sutherst, 2000) apples 2%, grapes 1%, pears 2.1% and oranges 2.2%		**$27,440**	**$25,626**	**$5,079**	**$35,031**	**$93,176**
Estimated Grower Annual Costs 88.6% of crop value (Sutherst, 2000)		$24,312	$22,704	$4,500	$31,037	$82,554
Estimated Government and Research Annual Costs 11.4% of crop value - (Note: Quarantine Inspection Cost 7.1% of crop value) (Sutherst, 2000)		$3,128	$2,921	$579	$3,994	$10,622
Number of Counties Identified to Support LBAM Life Cycle With Reported Acreage Greater than 0 in 2002		720	579	441	75	1,815

N/R - No crop value reported by USDA, National Agricultural Statistical Service.

Sources:
2002 U.S. Agricultural Census, Table 31 for Total Acreage
USDA, National Agricultural Statistical Service, Annual Noncitrus Fruits and Nuts, 2004 Summary, July 2005 for Value of Commercial Utilized Production
USDA, National Agricultural Statistical Service, Citrus Fruits, 2005 Summary, September 2005 for Value of Production
Sutherst, Robert W. 2000. Pests and Management Impact of Climate Change - A report for the Rural Industries Research and Development Corporation. RIRDC Publication No 00/16

Appendix 2. 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 3. 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 4. U.S. crop production (1,000s of hectares) from 1996 to 2005 (FAOSTAT, 2007).

Year	Apples	Oranges	Pears and Quinces	Grapes
1996	189.2	327.1	27.8	327.32
1997	189.39	341.4	27.06	338.02
1998	189.23	335.08	26.78	346.48
1999	186.49	335.9	26.76	366.13
2000	173.9	328.97	26.73	383.02
2001	169.18	329.74	26.33	377.36
2002	159.77	321.89	25.95	384.43
2003	158.01	320.39	25.96	384.86
2004	155.59	308.82	25.88	377.61
2005	153.32	298.5	25.15	378.32
Mean	172.408	324.779	26.440	366.355
SD	15.197	13.023	0.745	21.238
SD Proportion	0.088	0.040	0.028	0.058
3 SD Proportions	0.264	0.120	0.085	0.174

Appendix 5. 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	G	H
1	**Step**	**Value**	**Parameters**					
2	Commercial apple production value in LBAM at-risk areas	1,338,556,000	min/ml/max	985,177,216	1,338,556,000	1,691,934,784	3 SD	0.264
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	27,440,398						
5								
6	Commercial grape production value in LBAM at-risk areas	2,745,609,000	min/ml/max	2,267,873,034	2,745,609,000	3,223,344,966	3 SD	0.174
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	25,625,684						
9								
10	Commercial orange production value in LBAM at-risk areas	1,556,924,000	min/ml/max	1,370,093,120	1,556,924,000	1,743,754,880	3 SD	0.12
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	35,030,790						
13								
14	Commercial pear production value in LBAM at-risk areas	249,776,000	min/ml/max	228,545,040	249,776,000	271,006,960	3 SD	0.085
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	5,078,779						
17								
18	Total crop damage in LBAM at-risk areas	93,175,651						
19								
20	Relative quarantine cost proportion	0.080	min/ml/max	0.010	0.080	0.150		
21	Quarantine costs	7,454,052						
22								
23	Relative research cost proportion	0.049	min/ml/max	0.000	0.048	0.103		
24	Research Costs	4,581,136						
25								
26	Total costs from LBAM crop damage, quarantines and research	105,210,839						

Appendix 6. 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	G	H
1	**Step**	**Value**	**Parameters**					
2	Commercial apple production value in LBAM at-risk areas	=RiskPert(D2,E2,F2)	min/ml/max	=E2-(E2*H2)	1,338,556,000	=E2+(E2*H2)	3 SD	0.264
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	=E6-(E6*H6)	2,745,609,000	=E6+(E6*H6)	3 SD	0.174
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	=E10-(E10*H10)	1,556,924,000	=E10+(E10*H10)	3 SD	0.12
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	=E14-(E14*H14)	249,776,000	=E14+(E14*H14)	3 SD	0.085
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 7. 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 8. 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 9. 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 10. 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)				