The bioeconomics of the emerald ash borer invasion in Ohio and Michigan.

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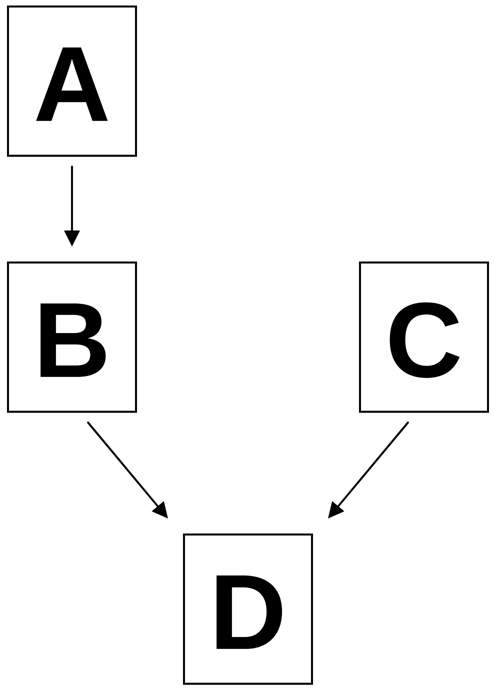
A bioeconomic framework for invasive species

- **Objectives:**
  - **1) to provide estimates of the regional economic impact an invasive species will potentially inflict;**
  - **2) to provide policy-makers with quantitative guidance for cost-effective alternative strategies to control, prevent, or slow the spread of an invasive species.**

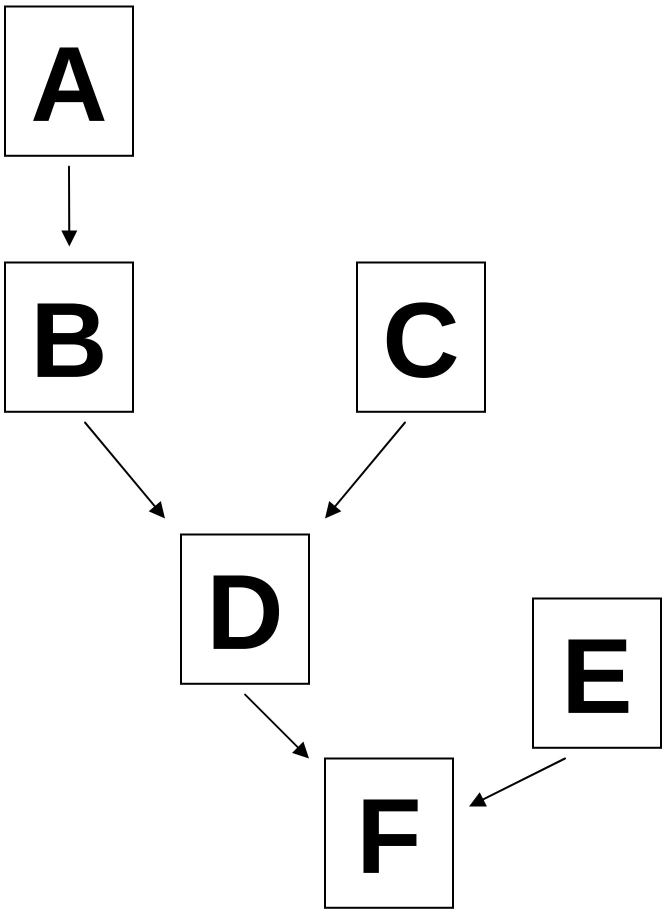
Objective 1: to provide estimates of the regional economic impact of an invasive species.

- *Estimate the potential habitat - A*
- *Predict the spread - B*
- *Estimate economic impact in a spatially explicit manner - C*
- *Determine the regional economic consequences of spread through the economy - D*



Objective 2: to provide policy-makers with quantitative guidance for cost-effective alternative strategies to control, prevent, or slow the spread of an invasive species.

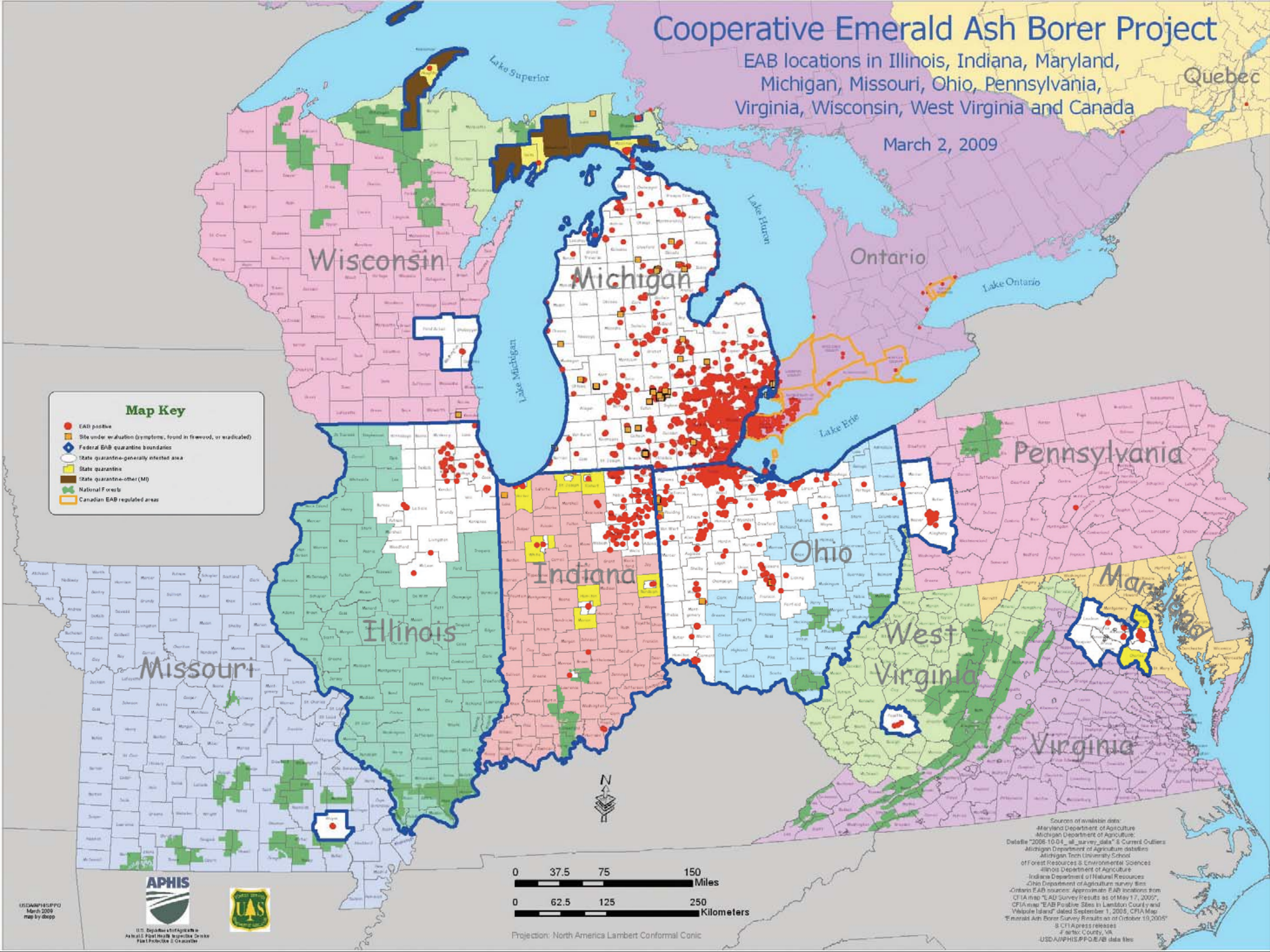
- *Determine cost and effectiveness of different prevention and control strategies - E*
- *Integrate habitat, spread, economics and management using Stochastic Dynamic Programming - F*



Native range of Emerald Ash Borer in Asia.

How did EAB arrive in North America?

- Arrived in solid wood packing material from Asia 10 -12 years ago.
- First detected in Detroit/Windsor area in July 2002.



Cooperative Emerald Ash Borer Project
EAB locations in Illinois, Indiana, Maryland, Michigan, Missouri, Ohio, Pennsylvania, Virginia, Wisconsin, West Virginia and Canada
March 2, 2009
Quebec
Lake Superior
Ontario
Lake Huron
Lake Ontario
Wisconsin
Michigan
Lake Michigan
Lake Erie
Pennsylvania
Map Key
EAB positive
Site under evaluation (symptoms, found in firewood, or eradicated)
Federal EAB quarantine boundaries
State quarantine-generally infested area
State quarantine
State quarantine-other (MI)
National Forests
Canadian EAB regulated areas
Illinois
Indiana
Ohio
Maryland
West Virginia
Missouri
Virginia
N
0 37.5 75 150 Miles
0 62.5 125 250 Kilometers
Projection: North America Lambert Conformal Conic
APHIS
USDA/APHIS/PPQ
March 2009
Sources of available data:
-Maryland Department of Agriculture
-Michigan Department of Agriculture:
Datafile "2006-10-04_all_survey_data" & Current Outliers
-Michigan Department of Agriculture datafiles
-Michigan Tech University School of Forest Resources & Environmental Sciences
-Illinois Department of Agriculture
-Indiana Department of Natural Resources
-Ohio Department of Agriculture survey files
-Ontario EAB sources: Approximate EAB locations from CFIA map "EAB Survey Results as of May 17, 2005", CFIA map "EAB Positive Sites in Lambton County and Walpole Island" dated September 1, 2005, CFIA Map "Emerald Ash Borer Survey Results as of October 19,2005" & CFIA press releases
-Fairfax County, VA
-USDA/APHIS/PPQ/EAB data files

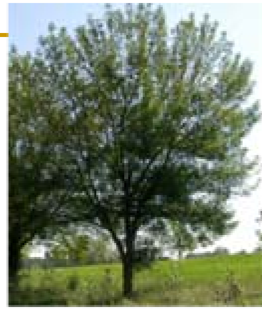
Effects of the EAB Invasion

- Over 40 million ash dead
- USDA has allocated $43.4 million for eradication
- Potential effects:
  - Estimated 3.8 billion white ash
  - $1 billion worth of standing ash timber
  - $2.3 million in nursery sales (1998). Estimated $20 million (2002)

Impacts


Millions of ash trees in suburban Detroit have been killed by the emerald ash borer.


0%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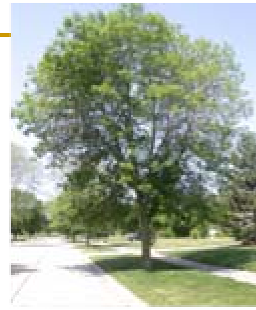
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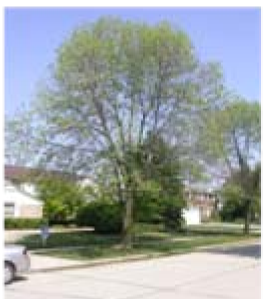

70%


80%


90%


100%

http://www.ipm.msu.edu/cat08land/l05-16-08.htm


http://www.naturalnewscapes.com/Quickstart/ImageLib/Insect-Emerald_defoliation.jpg

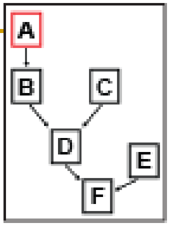

www.michigan.gov

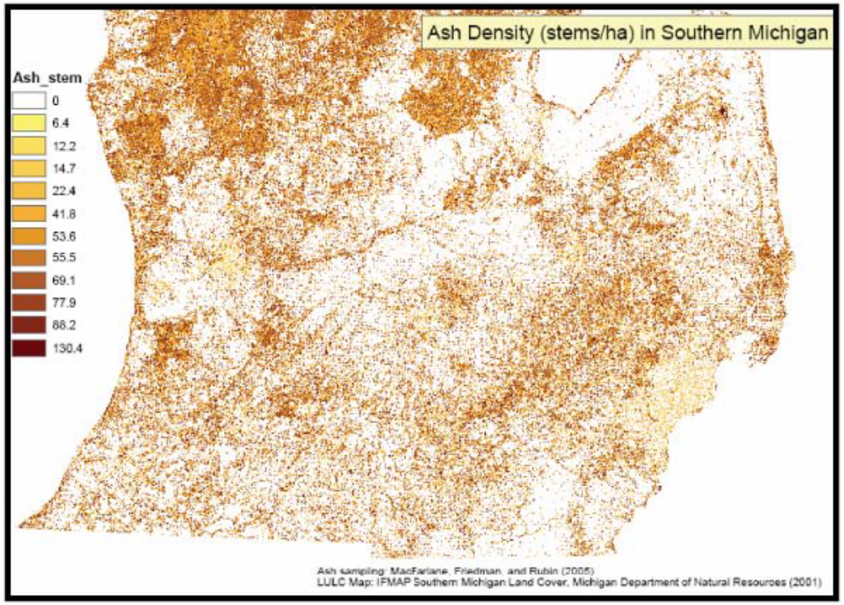
Symptoms of Emerald Ash Borer

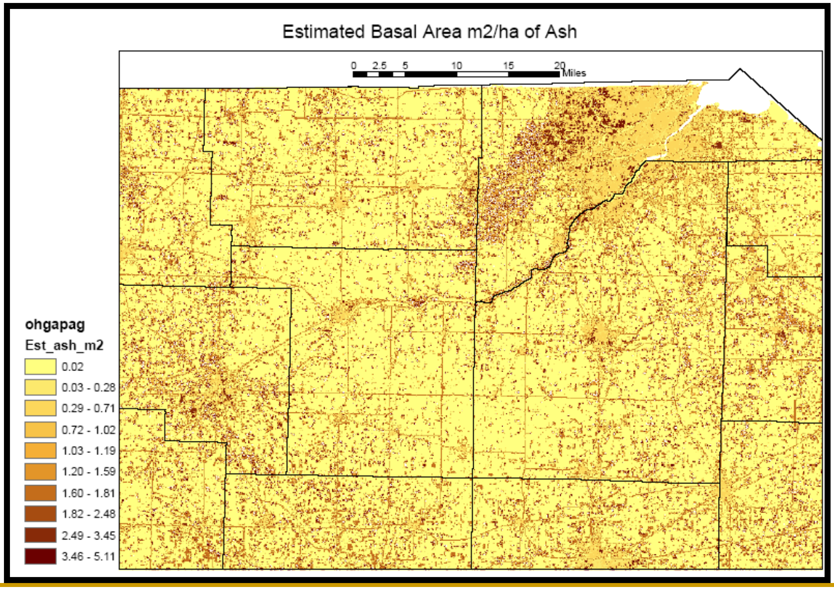
Galleries beneath bark

D-Shaped exit holes

Estimate the current distribution of ash trees and emerald ash borer





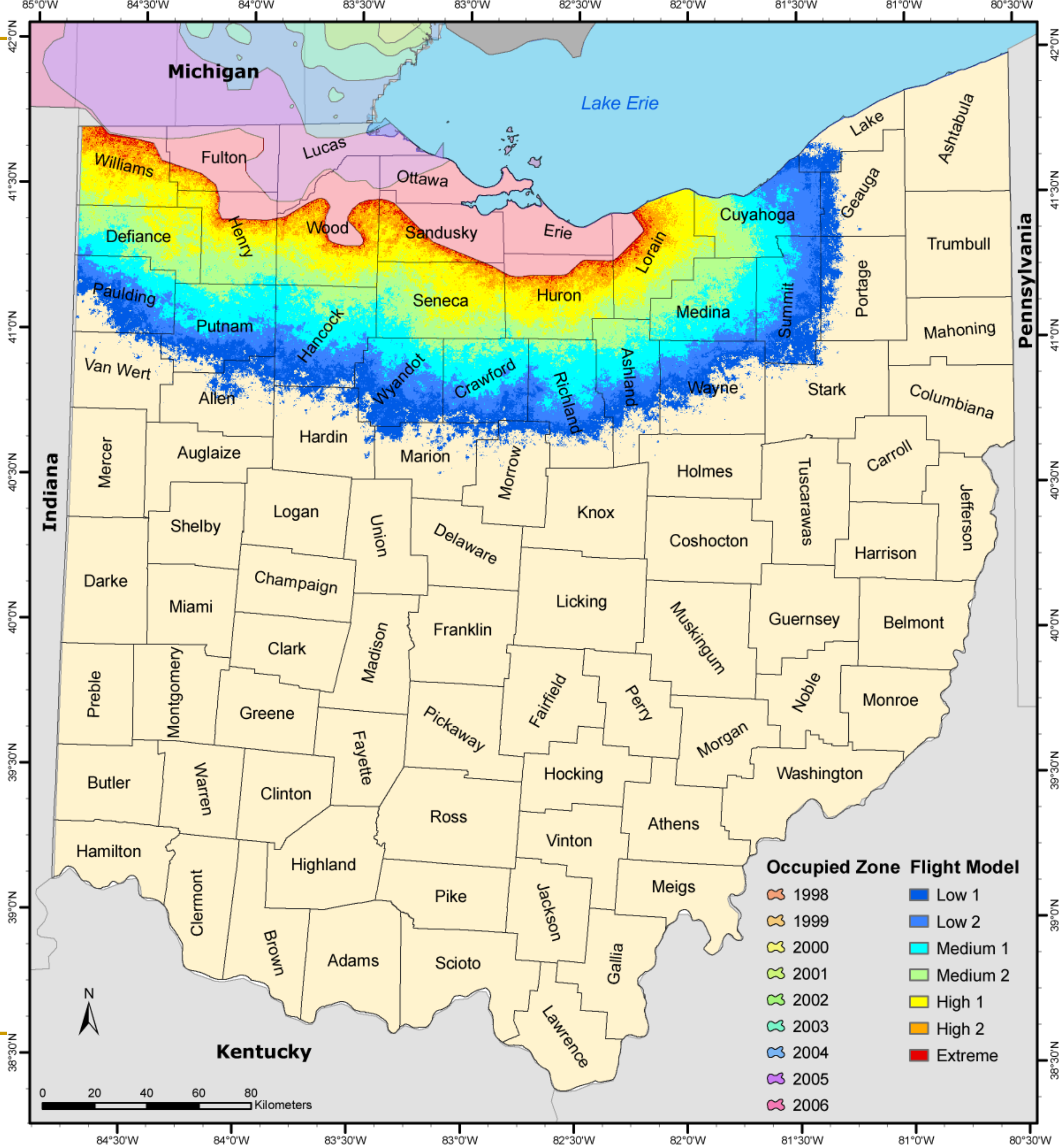


From Dr. Louis Iverson and Anatha Prasad - USFS

Predict the spread of emerald ash borer

- Local Dispersal
  - Flight (~2 km/yr)
  - Local human spread (~20 km/yr)

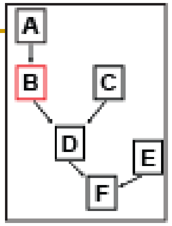
Natural Dispersal of EAB in Ohio



Iverson et al. unpublished data.

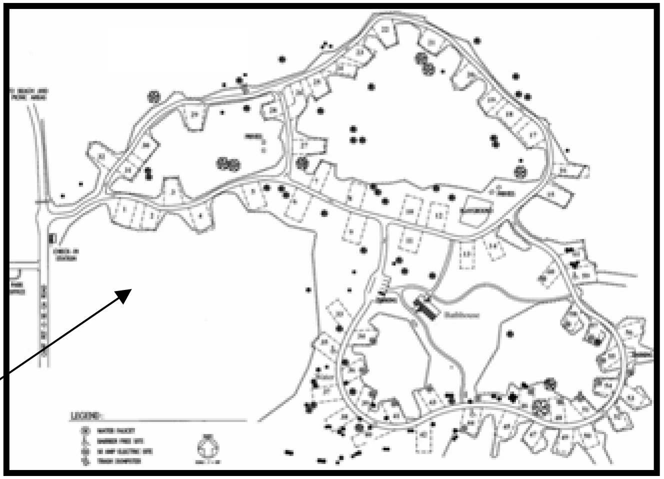
Predict the spread of emerald ash borer

- Local Dispersal
  - Flight (~2 km/yr)
  - Local human spread (~20 km/yr)
- Human-mediated dispersal
  - Campers moving firewood
  - Hitchhikers on cars, trucks, etc.
    - i.e. road networks.
  - Wood products industry



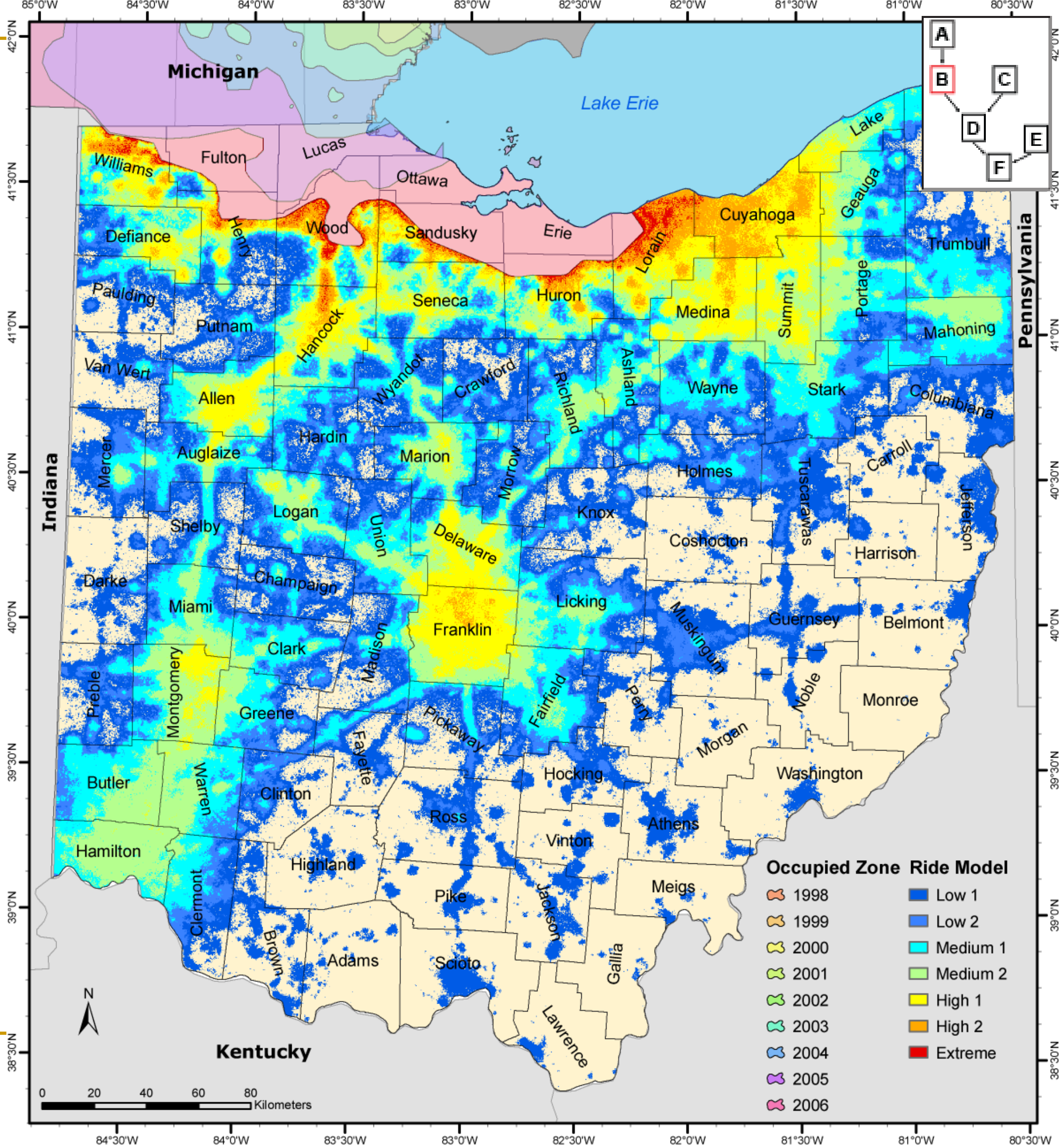
Predict the spread of emerald ash borer: Human-mediated dispersal

$$U_{ij} = \sum_{i=1}^{K} A_i O_i W_j D_{ij}^{-d}$$



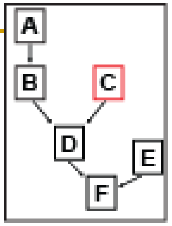
Campers with Firewood

Natural and Human-Mediated Dispersal of EAB in Ohio



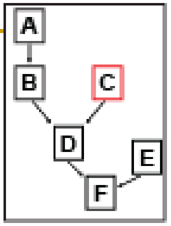
Iverson et al. unpublished data.

Estimate value of ash in spatially explicit manner



- Impact on Communities
  - Tree City USA program – to estimate urban values.
- Forest products:

The Potential Economic Impacts of Emerald Ash Borer (*Agrilus planipennis*) on Ohio, U.S., Communities



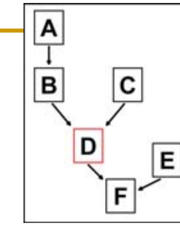
T. Davis Sydnor, Matthew Bumgardner, and Andrew Todd

Arboriculture & Urban Forestry 2007. 33(1):48–54.

	Landscape Values	Tree Removal Costs	Replacement Costs
Street Trees	16,543	13,838	5,945
Park Trees	25,724	22,968	11,101
Private Trees	258,982	216,621	93,067
Totals	301,249	253,427	110,113

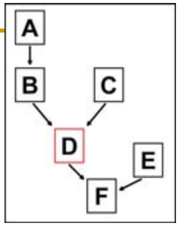
Potential losses per 1000 residents in dollars. Adapted from Sydnor et al. (2007)

Regional economic consequences of the spread of the emerald ash borer

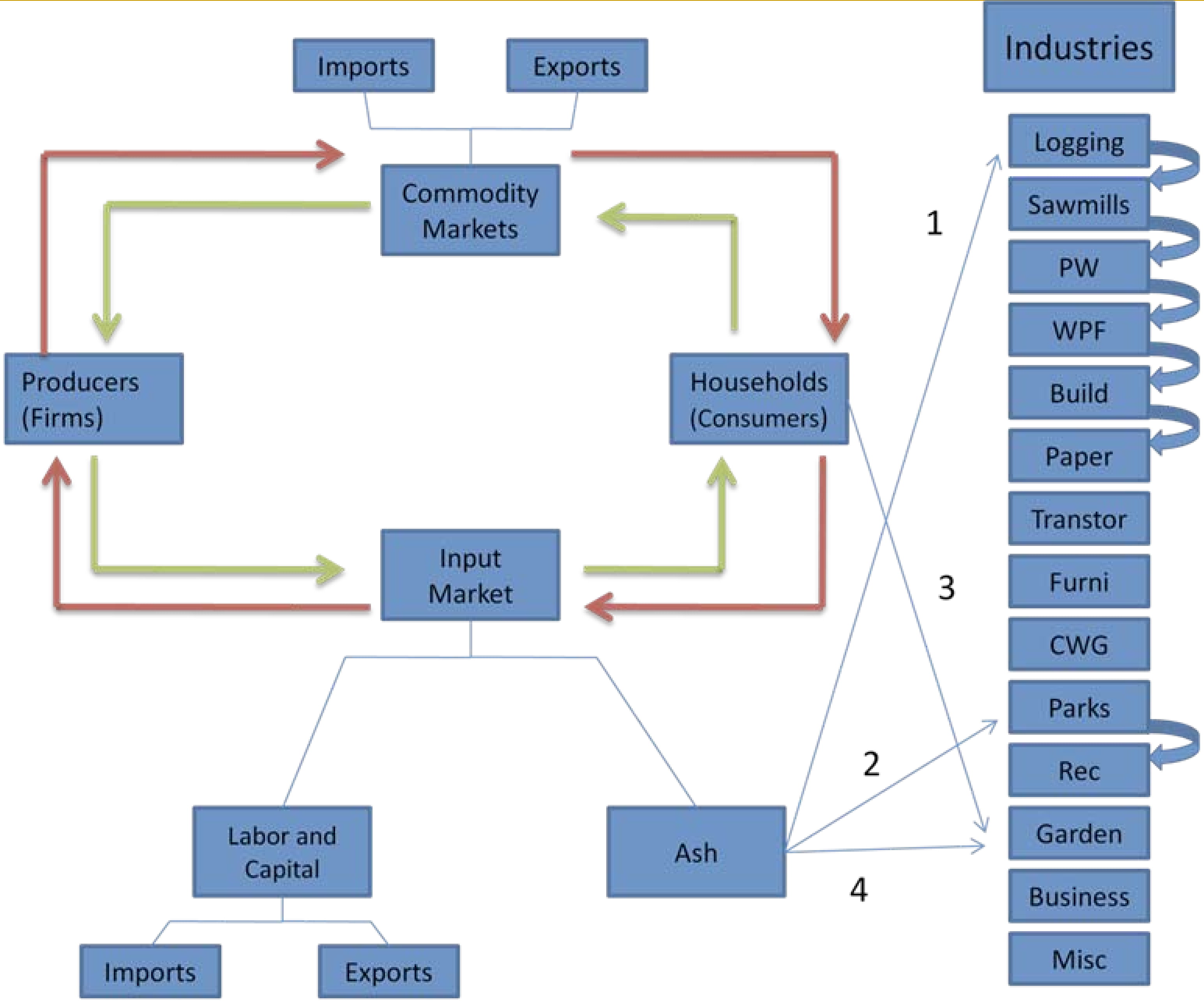


- Objective:
  - Address the regional welfare consequences in Ohio and Michigan from the loss of ash harvest using a Computable General Equilibrium (CGE) model.
- Estimating the impact from an invasion of EAB requires incorporating 4 items properly:
  - The economic sectors affected by ash harvest, which are vertically integrated.
    - Adjustments in production represent changes in each sector’s optimal production bundle.
  - The cost impact on parks and recreation.
  - Household and state income impacts due to the removal costs of ash trees.
  - Demand impacts to account for the additional demand on the garden sector.

Regional economic consequences of the spread of the emerald ash borer



- A multi-sector general equilibrium model with inter-industry linkages, factor markets, households, government receipts and expenditures, and trade.
  - The aggregated industries include:
    - logging, sawmills, processed wood, finished wood products, building, business services, transportation/storage, furniture, consumer wood goods, recreation, paper, garden stores, parks, and miscellaneous.
  - Firms use inputs of factors and intermediate goods via a Leontief production function.
  - Factor markets consist directly of labor and capital, and indirectly of ash and technology.
  - Households are linked to industries through commodity and factor markets. Household utility is given by nested CES functions.
  - Government interactions are accounted for as government redistribution schemes.

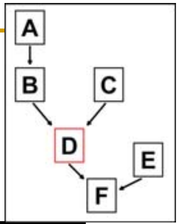


Green arrows= monetary flows
Red arrows= real flows

Regional economic consequences of the spread of the emerald ash borer

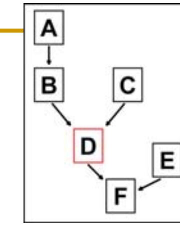
- In equilibrium agents make optimal decisions while linked to each other such that prices adjust and no excess demand exists.

Annual Impacts



Summary of Annual Median Impact From Complete Loss of Ash Harvest		
Mode of Impact	Average Welfare Impact	
	MI	OH
Vertically Integrated Production (excluding Parks and Recreation Sectors)	-$3.801 million	-$2.85 million
Parks and Recreation Cost Impact	-$3.701 million	-$2.95 million
Household Income Reduction	-$49.93 million	-$51.92 million
Garden Sector Demand Increase (HH)	$6,665	$5,924
State Cost Impact	-$537,500	-$492,400
Garden Sector Demand Increase (State)	$1,320	$847
Total Annual Impact	-$57.96 million	-$58.20 million

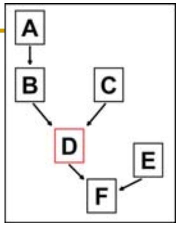
Annual Impact Per Household



Annual Michigan Overall Impacts Per Household		
	Average Income	**Average Impact (over 7,776 scenarios)**
HHD1	$4,951.31	-$0.46
HHD2	$12,378.24	-$0.13
HHD3	$19,805.20	-$0.21
HHD4	$29,707.78	-$14.34
HHD5	$42,086.02	-$15.59
HHD6	$69,318.19	-$17.87
HHD7	$89,123.40	-$19.41
HHD8	$123,782.47	-$21.96
HHD9	$173,295.49	-$24.82

Annual Ohio Overall Impacts Per Individual Household		
	Average Income	**Average Impact (over 7,776 scenarios)**
HHD1	$6,342.55	$0.91
HHD2	$15,856.47	$0.26
HHD3	$25,370.19	-$0.40
HHD4	$38,055.38	-$14.32
HHD5	$53,911.73	-$15.21
HHD6	$88,795.80	-$17.08
HHD7	$114,166.07	-$17.81
HHD8	$158,563.95	-$19.84
HHD9	$221,989.53	-$22.35

CGE Results over 10 years:



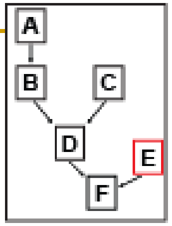
- For Ohio, the total net present value of damages is $457 million.
- For Michigan, the total net present value of damages is $461 million.
  - However, a static model is inapt for calculating total economic impacts because behavioral adaptations to a loss of ash occur over time.

- This CGE model introduces more in depth welfare impacts by looking at specific income groups.
  - Previous welfare estimates do not take into account the effect of price adjustments from a loss of ash.
  - Other models that keep prices fixed will overestimate the welfare impacts and lack the detail that the CGE model provides.
  - Both welfare estimates are more than half of the projected losses from previous fixed price models.

Objective 2: provide policy-makers with quantitative guidance for cost-effective alternative strategies to control, prevent, or slow the spread of emerald ash borer.

- *Determine cost and effectiveness of different prevention and control strategies*

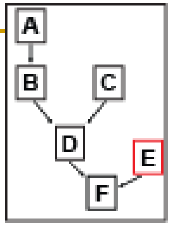
- *Link distribution and spread models with CGE to optimize resources*



- *Determine cost and effectiveness of different prevention and control strategies*

- Examined eradication for 2 scenarios:
  - 1) How much would it have been worth to stop the spread initially in Michigan?
    - Does this depend on who is making the decisions?
  - 2) How long would damages be delayed in Ohio.

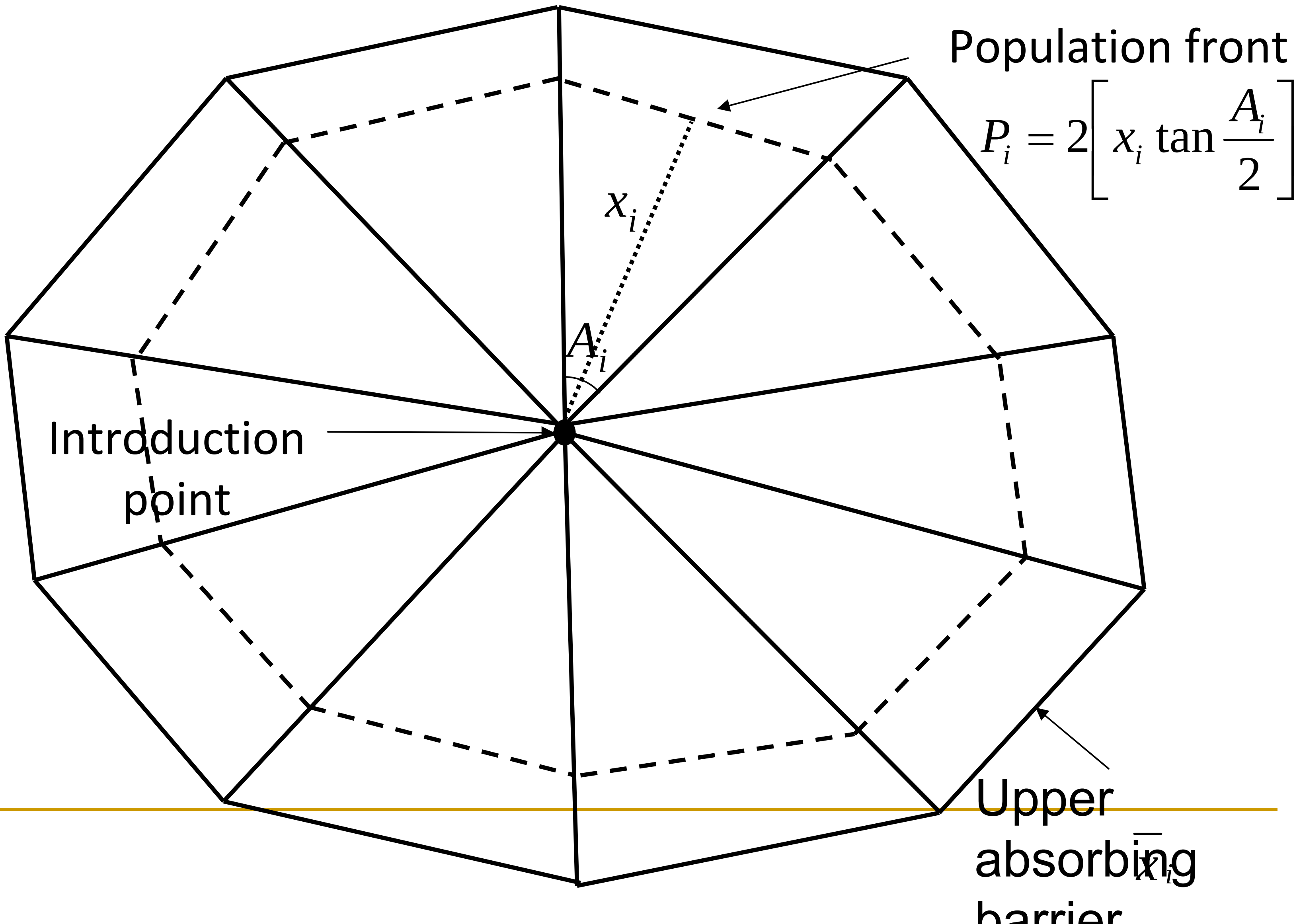
Real options model



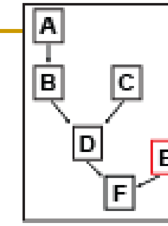
- Real options ideal for evaluating invasive policies
  1. Uncertain spread of invasive species
  2. Control cost irreversible
  3. Policy adoption can be delayed to obtain more information
     - Results of Real Options models are dependent of the specifications of the stochastic spread process.
- Used Geometric Brownian motion (GBM)
  - Pros
    - Non-constant drift rate consistent with stratified dispersal
    - Explicit solution for investment threshold *D**
  - Cons
    - Assumes process is unbounded above
- Barriers arise due to natural and geopolitical boundaries
- GBM may overestimate pest damages and bias decision making by allowing infinite population levels

Invasive species spread

$$dx_i = r_i^1 x_i dt + s_i x_i dz$$



Damages and control costs



- Monetary damages from invasive species:

$$D_i = \gamma x_i^{\theta}$$

where $\gamma > 0$ and $\theta > 1$

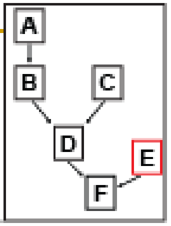
- Assume r^1 can be reduced to r^2 with cost

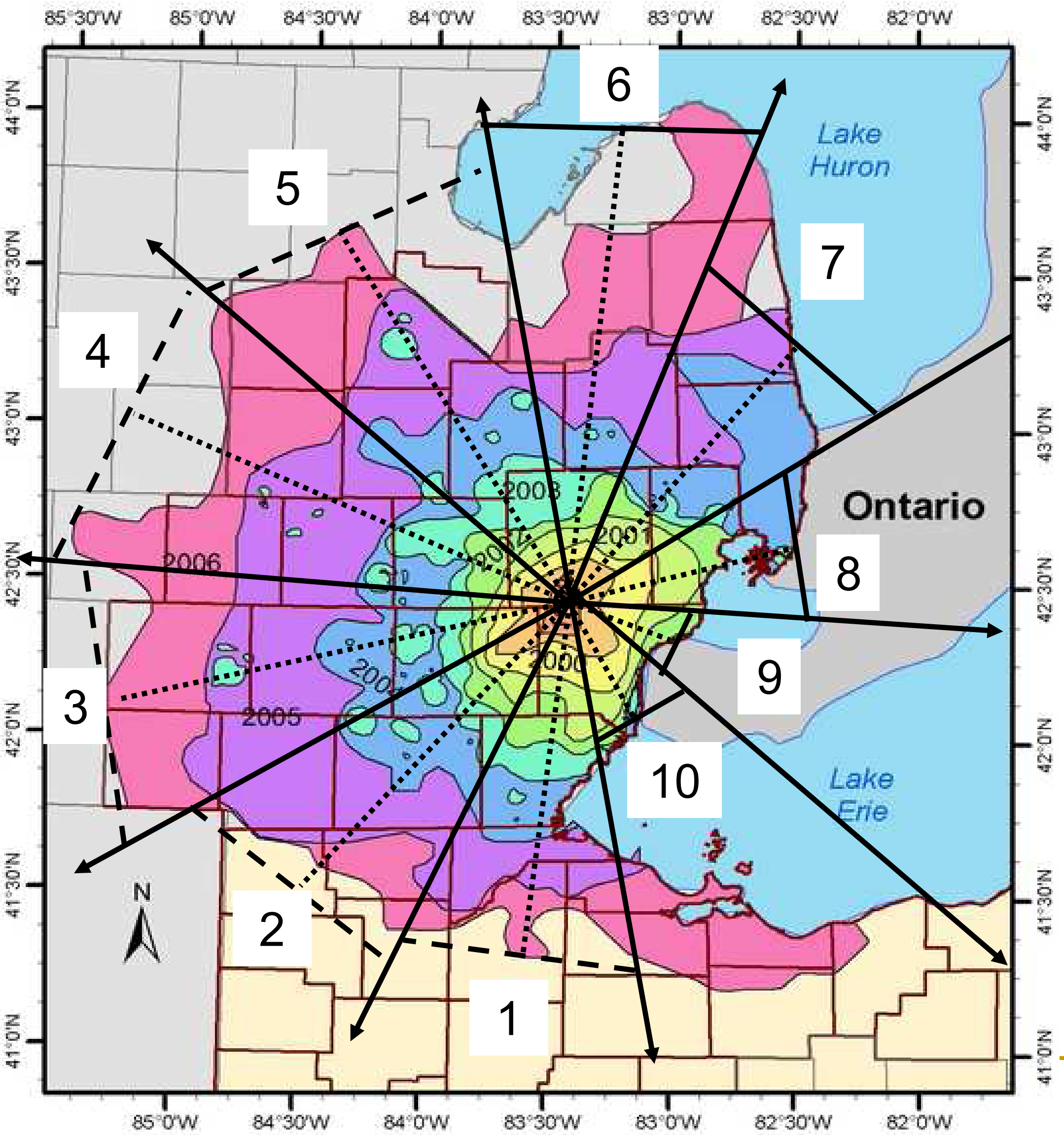
$$C_i = \upsilon P_i^{a} \left(r_i^1 - r_i^2\right)^b$$

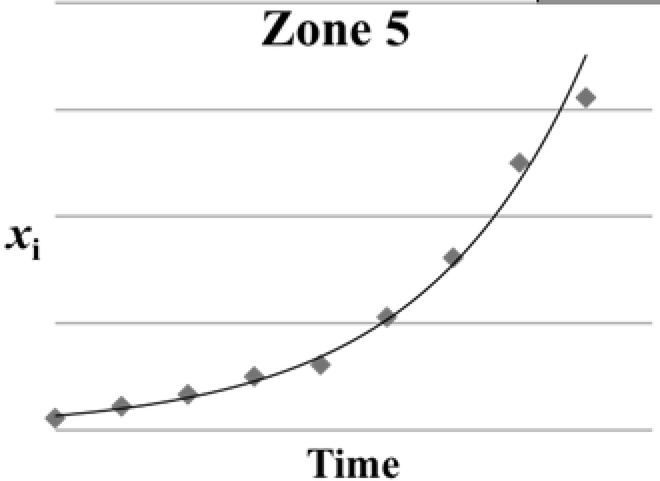
where $\upsilon > 0$, $a \leq 1$, and $b > 1$

- Damages and control costs evolve according to GBM with upper barriers at $\overline{D}_i$ and $\overline{C}_i$
- *Objective: Choose optimal degree of control* $r_i^{2^*}$ *and optimal time to control* D_i^*

Application to emerald ash borer

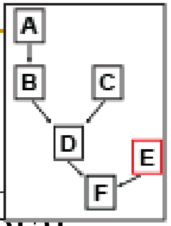






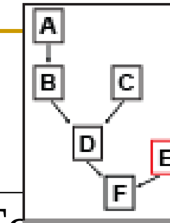
	r^1	s
1	0.46	0.15
2	0.23	0.11
3	0.30	0.12
4	0.41	0.15
5	0.47	0.17
6	0.49	0.14
7	0.48	0.18

Optimal EAB control policies



	Management zone							Total control cost
	1	2	3	4	5	6	7	
Federal level control: upper barrier corresponds to US border or lake								
reduction in spread rate	95.9%	92.0%	91.0%	86.7%	92.5%	0.4%	0.02%	$2 billion
r_i^2*	0.02	0.02	0.03	0.05	0.04	0.49	0.48	

Optimal EAB control policies



	Management zone							Total control cost
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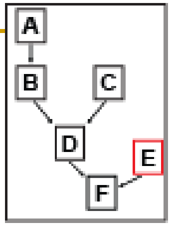
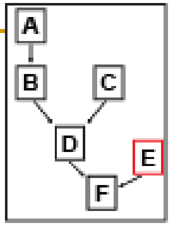
Federal level control: upper barrier corresponds to US border or lake								
reduction in spread rate	95.9%	92.0%	91.0%	86.7%	92.5%	0.4%	0.02%	$2 billion
r_i^2*	0.02	0.02	0.03	0.05	0.04	0.49	0.48	
State level control: upper barrier corresponds to Michigan border or lake								
reduction in spread rate	0.0%	0.3%	85.7%	86.7%	92.5%	0.4%	0.02%	$1.1 billion
r_i^2*	0.46	0.23	0.04	0.05	0.04	0.49	0.48	

Take home points



- Ignoring barriers to spread severely overestimates optimal control expenditures
- Level of decision making (state, federal) impacts total expenditures and location of control efforts
- Spatial dynamic control externality helps perpetuate invasive species spread



- *Determine cost and effectiveness of different prevention and control strategies*

- Examined eradication for 2 scenarios:
  - 1) How much would it have been worth to stop the spread initially in Michigan?
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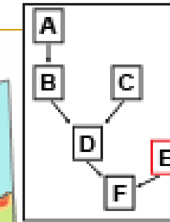
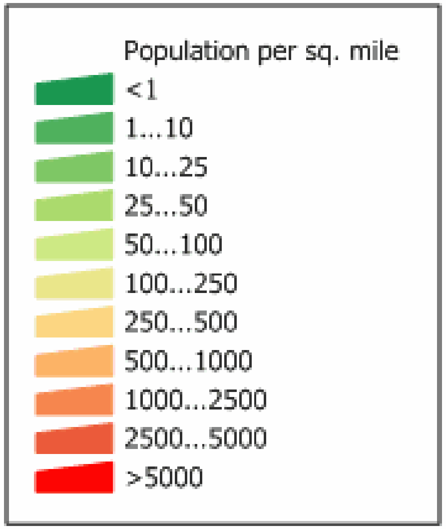
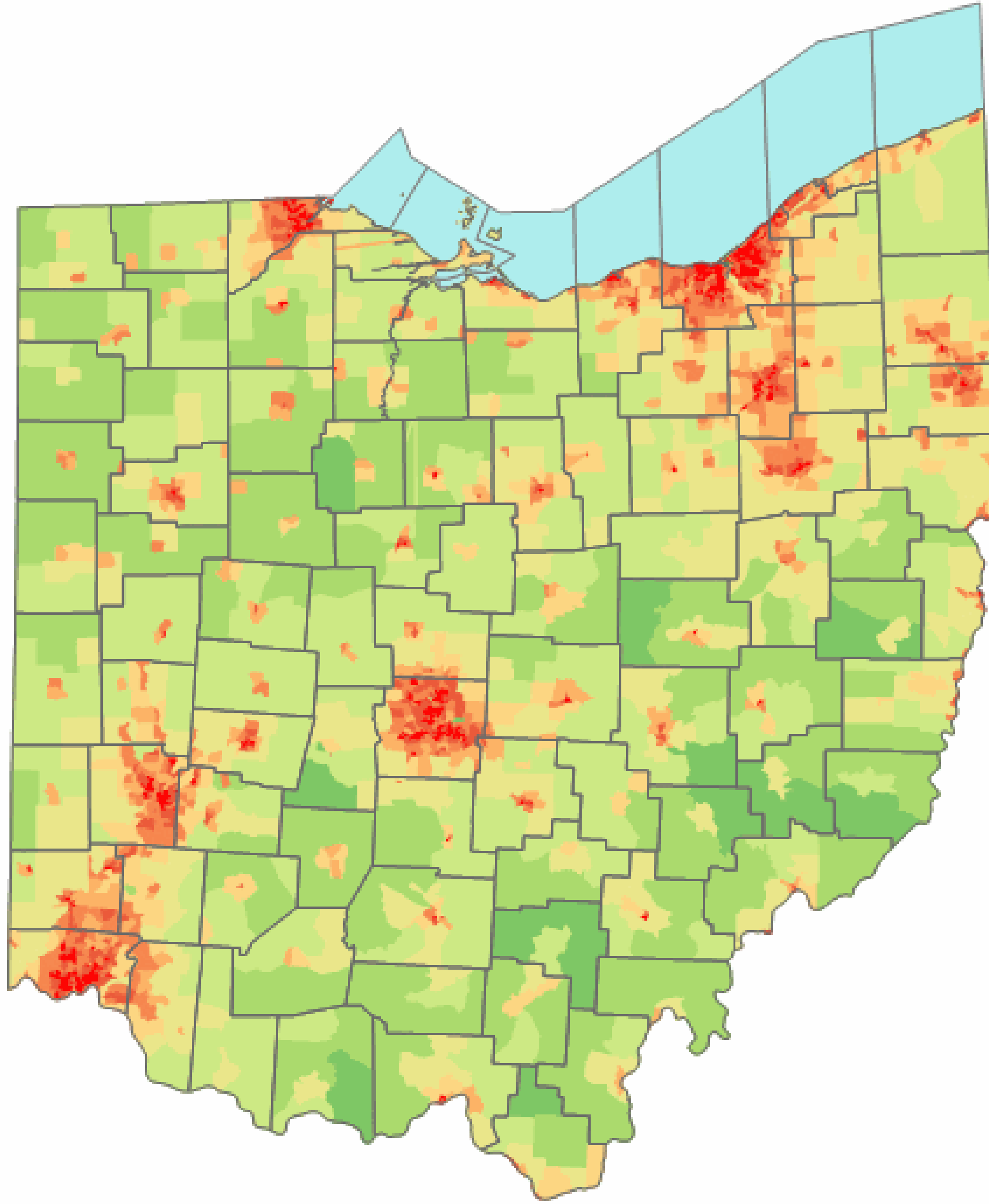
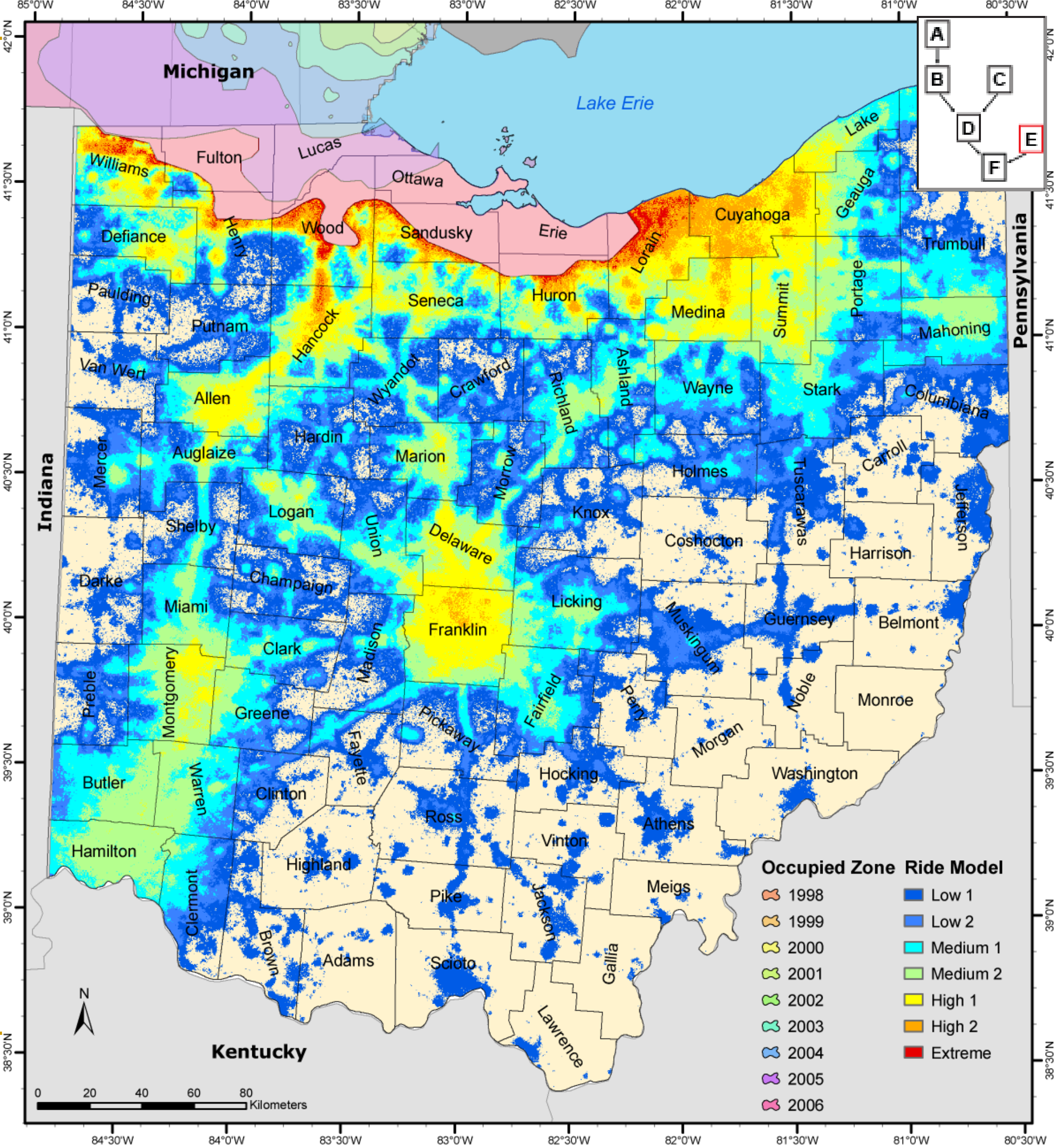




Source: U. S. Census Bureau
Census 2000 Summary File 1
population by census tract.



Natural and Human-Mediated Dispersal of EAB in Ohio



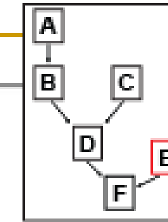
Iverson et al. unpublished data.

Spread model with eradication

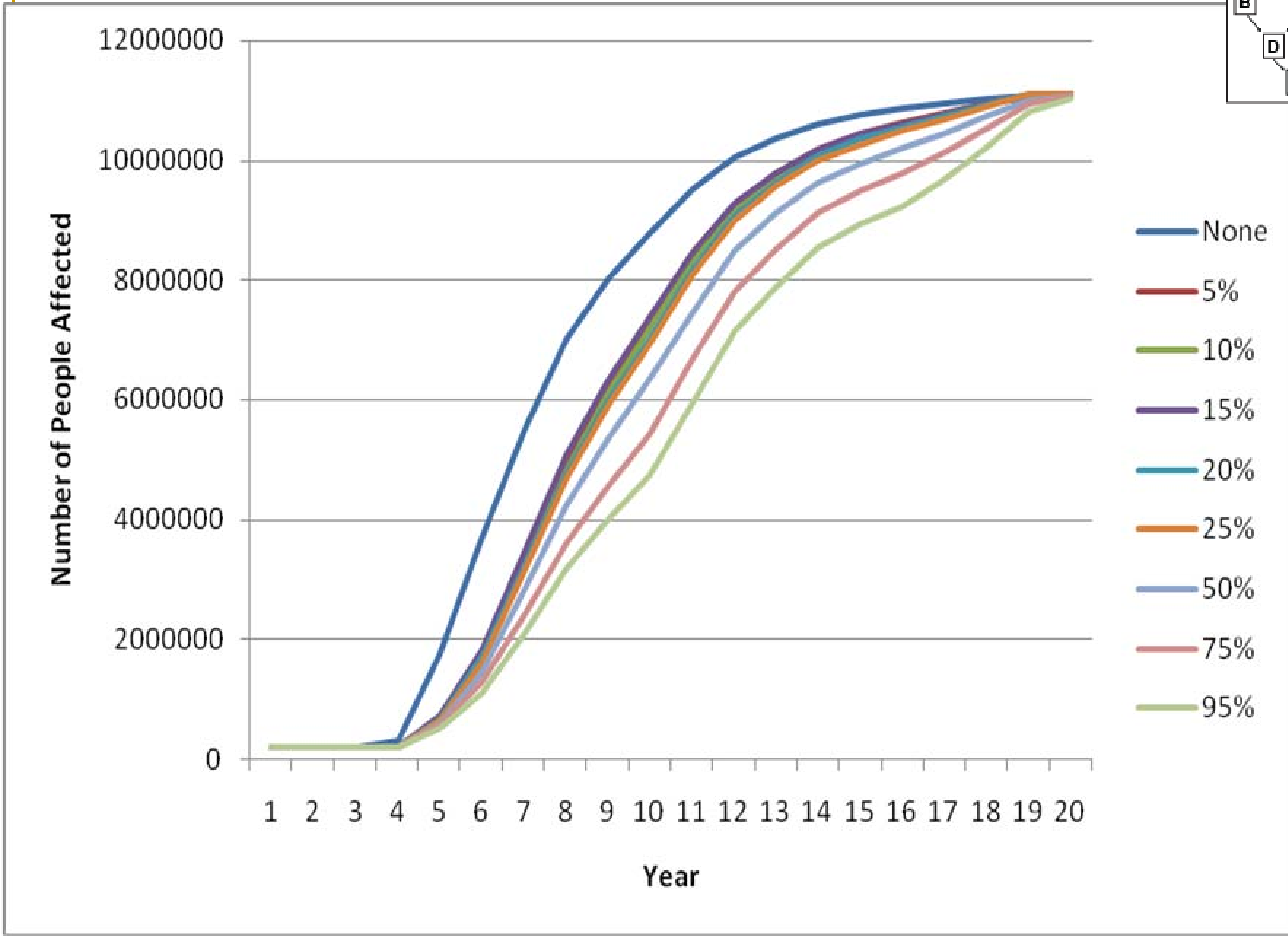
- Using the following model we assessed how much the spread of EAB would be slowed if long-distance infestation events were eradicated.

$$I_X = Bernoulli\left(ls * \left(risk_X\right)\right) + Bernoulli\left(d_X * ws\right)$$

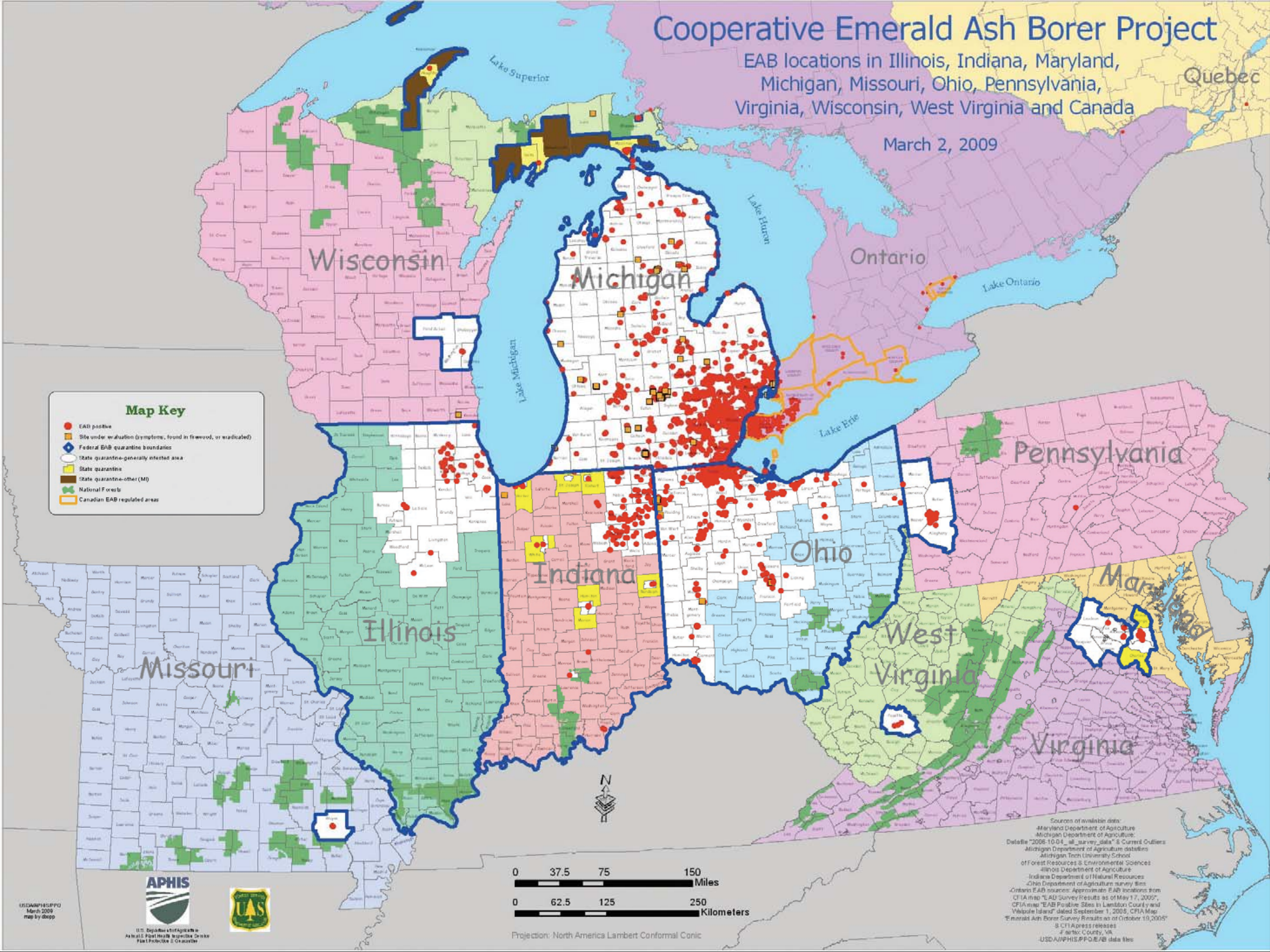
- I_X - infestation status
- ls = a long distance scalar
- $risk_X$ = risk value
- d_X = distance of location x from the wave front
- ws = wave front spread parameter



A
B
C
D
E
F

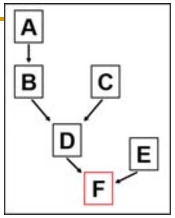


Number of People Affected
12000000
10000000
8000000
6000000
4000000
2000000
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Year
None
5%
10%
15%
20%
25%
50%
75%
95%



Cooperative Emerald Ash Borer Project
EAB locations in Illinois, Indiana, Maryland, Michigan, Missouri, Ohio, Pennsylvania, Virginia, Wisconsin, West Virginia and Canada
March 2, 2009
Lake Superior
Lake Michigan
Lake Huron
Lake Ontario
Lake Erie
Quebec
Ontario
Wisconsin
Michigan
Pennsylvania
Ohio
Indiana
Illinois
Missouri
West Virginia
Maryland
Virginia
Map Key
EAB positive
Site under evaluation (symptoms, found in firewood, or eradicated)
Federal EAB quarantine boundaries
State quarantine-generally infested area
State quarantine
State quarantine-other (MI)
National Forests
Canadian EAB regulated areas
N
0 37.5 75 150 Miles
0 62.5 125 250 Kilometers
Projection: North America Lambert Conformal Conic
Sources of available data:
-Maryland Department of Agriculture
-Michigan Department of Agriculture:
Datafile "2006-10-04_all_survey_data" & Current Outliers
-Michigan Department of Agriculture datafiles
-Michigan Tech University School
of Forest Resources & Environmental Sciences
-Illinois Department of Agriculture
-Indiana Department of Natural Resources
-Ohio Department of Agriculture survey files
-Ontario EAB sources: Approximate EAB locations from
CFIA map "EAB Survey Results as of May 17, 2005",
CFIA map "EAB Positive Sites in Lambton County and
Walpole Island" dated September 1, 2005, CFIA Map
"Emerald Ash Borer Survey Results as of October 19,2005"
& CFIA press releases
-Fairfax County, VA
-USDA/APHIS/PPQ/EAB data files
APHIS
USDA/APHIS/PPQ
March 2009
map by dbopp
U.S. Department of Agriculture
Animal & Plant Health Inspection Service
Plant Protection & Quarantine

Link distribution and spread models with CGE to optimize resources.



- …where we are headed.
  - Linking Real Options Model with number of people impacted rather than area impacted.
  - Including distribution of ash and urban areas in Real Options Model.

Conclusions

- Human-mediated dispersal is important for the spread of emerald ash borer.
- Eradication not likely to stop spread, but could slow the economic impact.
- It would have been worth over $1 billion to slow the initial spread of the emerald ash borer in Michigan.
- This invasion is and will continue to cause millions in welfare loss to Ohio, Michigan and beyond.

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Ohio Annual Impacts

Table 1: Summary of Annual Ohio Median Impact From Complete Loss of Ash Harvest	
Mode of Impact	Average Welfare Impact
Vertically Integrated Production (excluding Parks and Recreation Sectors)	-$2.85 million
Parks and Recreation Cost Impacts	-$2.95 million
Household Income Reduction	-$51.92 million
Garden Sector Demand Increase (HH)	$5,924
State Cost Impact	-$492,400
Garden Sector Demand Increase (State)	$847
Total Annual Impact	-$58.20 million

Ohio Annual Impact Per Household

Table 2: Annual Ohio Overall Impacts Per Individual Household				
	Average Income	**Minimum Impact (Logging Affected Only)**	**Maximum Impact (All Industries Affected)**	**Average Impact (over 7,776 scenarios)**
HHD1	$6,342.55	$1.13	$0.69	$0.91
HHD2	$15,856.47	$0.31	$0.20	$0.26
HHD3	$25,370.19	-$0.42	-$0.37	-$0.40
HHD4	$38,055.38	-$14.31	-$14.32	-$14.32
HHD5	$53,911.73	-$15.11	-$15.32	-$15.21
HHD6	$88,795.80	-$16.81	-$17.36	-$17.08
HHD7	$114,166.07	-$17.34	-$18.28	-$17.81
HHD8	$158,563.95	-$19.19	-$20.49	-$19.84
HHD9	$221,989.53	-$21.48	-$23.22	-$22.35

Michigan Annual Impacts

Table 2: Summary of Annual Michigan Median Impact From Complete Loss of Ash Harvest	
Mode of Impact	Average Welfare Impact
Vertically Integrated Production (excluding Parks and Recreation Sectors)	-$3.801 million
Parks and Recreation Cost Impact	-$3.701 million
Household Income Reduction	-$49.93 million
Garden Sector Demand Increase (HH)	$6,665
State Cost Impact	-$537,500
Garden Sector Demand Increase (State)	$1,320
Total Annual Impact	-$57.96 million

Michigan Annual Impact Per Household

Table 32: Annual Michigan Overall Impacts Per Household				
Equivalent Variation (EV)	**Average Income**	**Minimum Impact (Logging Affected Only)**	**Maximum Impact (All Industries Affected)**	**Average Impact (over 7,776 scenarios)**
HHD1	$4,951.31	-$0.21	-$0.70	-$0.46
HHD2	$12,378.24	-$0.08	-$0.18	-$0.13
HHD3	$19,805.20	-$0.24	-$0.19	-$0.21
HHD4	$29,707.78	-$14.32	-$14.36	-$14.34
HHD5	$42,086.02	-$15.42	-$15.75	-$15.59
HHD6	$69,318.19	-$17.48	-$18.26	-$17.87
HHD7	$89,123.40	-$18.79	-$20.03	-$19.41
HHD8	$123,782.47	-$21.09	-$22.84	-$21.96
HHD9	$173,295.49	-$23.64	-$26.01	-$24.82

Discussion

- A static model is inapt for calculating total economic impacts because behavioral adaptations to a loss of ash occur over time.
- Given these limitations, a back of the envelope calculation of the dynamic consequences using the annual estimates can be done.
  - For Ohio, the total net present value of damages is $457 million.
  - For Michigan, the total net present value of damages is $461 million.
- This CGE model introduces more in depth welfare impacts by looking at specific income groups.
  - Previous welfare estimates do not take into account the effect of price adjustments from a loss of ash.
  - Other models that keep prices fixed will overestimate the welfare impacts and lack the detail that the CGE model provides.
  - Both welfare estimates are more than half of the projected losses from previous fixed price models.
- Detailed welfare impacts are necessary when deciding mitigation policies for EAB or other ecological invasions.
- There are many ways to extend this analysis.
  - The next step is look at the policy for eradicating and preventing the spread of EAB.
- This paper is capable of increasing the momentum for future invasive species research.

Works Cited

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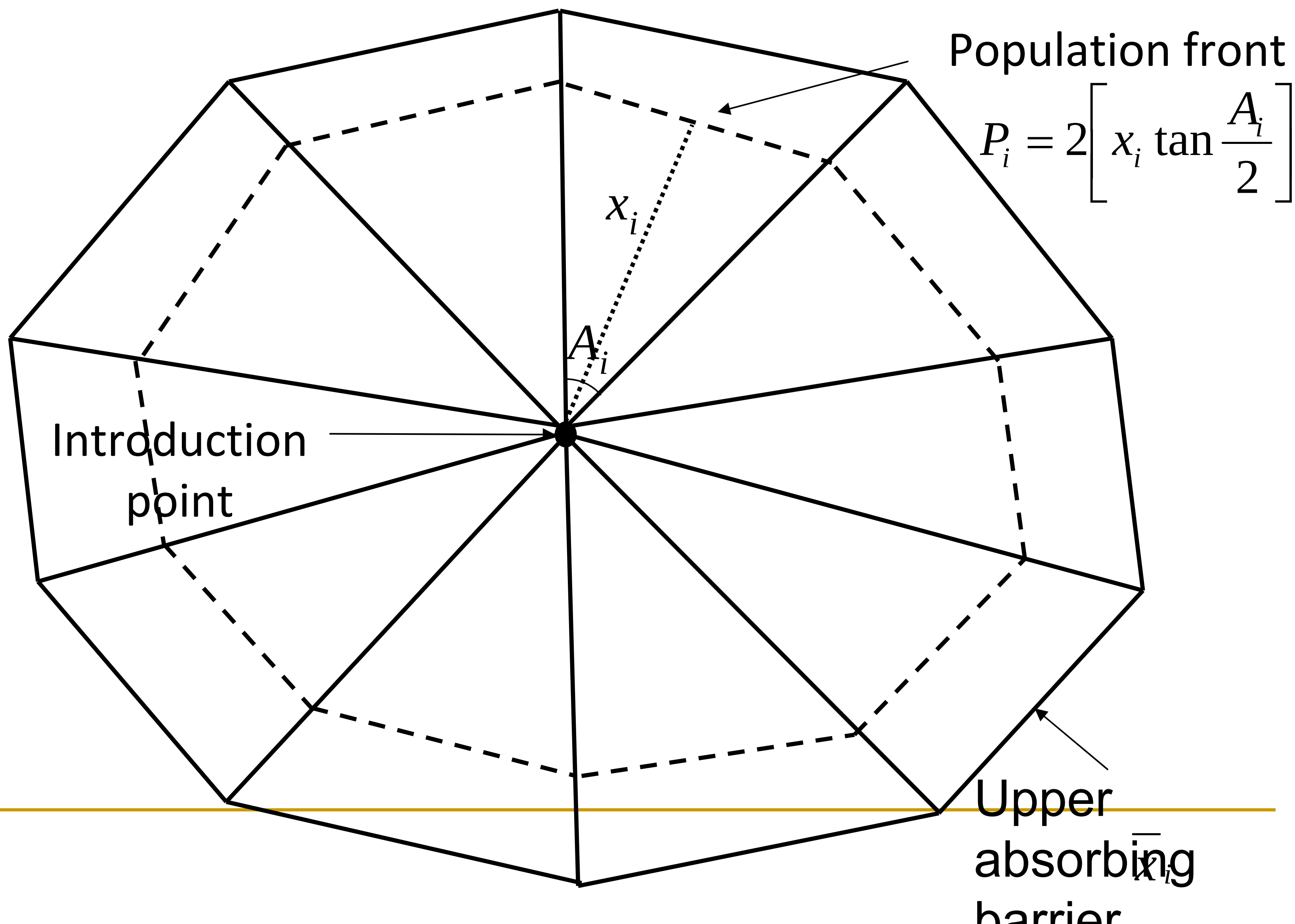
Invasive species spread

$$dx_i = r_i^1 x_i dt + s_i x_i dz$$



Optimal EAB control policies

	Management zone							Total control expenditures
	1	2	3	4	5	6	7	
Optimal control of unbounded invasion: no upper barrier								
% reduction in spread rate	96.6	92.3	91.6	95.1	95.8	95.1	96.5	$3.4 billion
r_i^2*	0.02	0.02	0.03	0.02	0.02	0.02	0.02	
Federal level control: upper barrier corresponds to US border or lake								
% reduction in spread rate	95.9	92.0	91.0	86.7	92.5	0.4	0.02	$2 billion
r_i^2*	0.02	0.02	0.03	0.05	0.04	0.49	0.48	
State level control: upper barrier corresponds to Michigan border or lake								
% reduction in spread rate	0.0	0.3	85.7	86.7	92.5	0.4	0.02	$1.1 billion
r_i^2*	0.46	0.23	0.04	0.05	0.04	0.49	0.48	