



Department  
for Environment  
Food & Rural Affairs

# Categorically Uncertain:

## How Bayesian belief networks help when you're not sure which box to tick

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# Approaches to Pest Risk Analysis

- ISPM 2, ISPM 11 provide a framework: things to consider in PRA
  - do not say how to do PRA
- Several NPPOs have adapted ISPM 11 into questions
- Allows for consistent systematic approach to inform decision making
- If not fully quantitative risk assessor evaluates risk elements; selects a rating from ordinal scale
  - Low, Medium, High
  - very Low, Low, Medium, High, very High
- Ratings / scores combine to generate an assessment of risk to inform decision making

# Stages in Pest Risk Analysis

## 1. INITIATION

- Identity of pest
- Reason for PRA
- Identify PRA area



## 2. RISK ASSESSMENT

- Host Plants *Gathering evidence*
- Geographical Distribution (biology of the pest)



*Interpreting evidence*

- Capable of introduction ? (entry & establishment)
- Spread & potential impact?
- Overall risk



## 3. RISK MANAGEMENT

- Management options (Consultation)
- Monitoring and review of measures



# Conventional approaches

- Traditionally, PRA relies on structured questionnaires that use categorical or scored responses to evaluate risk elements such as likelihood of entry and establishment, and magnitude of spread and impact
- Must select one rating from a range of options when assessing each element of risk even when evidence is ambiguous or incomplete
- Risk elements are combined to produce an overall risk category or score

## What is the likelihood of entry on each pathway?

(provide reasoning then select box that represents the most appropriate likelihood)

Pathway 1      Very unlikely       Unlikely       Moderately likely       Likely       Very likely

Pathway 2      Very unlikely       Unlikely       Moderately likely       Likely       Very likely

## How likely is the pest to establish outdoors in the PRA area?

(provide reasoning then select box)

Establish outdoors      Very unlikely       Unlikely       Moderately likely       Likely       Very likely

# Common challenges

- Very often assessors lack data to be confident the correct rating is chosen
- Use judgement to select a rating / category
- Allows opinion and subjectivity
- Approach struggles to address uncertainty in assessor responses
- Hard to understand how much confidence to place in results
- Difficulty in identifying knowledge gaps
- Conventional risk matrices do not deal with input uncertainty e.g. which score / category to select when there is imperfect knowledge or conflicting evidence

# Biosecurity Australia

- Likelihood elements: Importation, Distribution, Establishment, Spread
- For each select from Negligible, Extremely low, Very low, Low, Moderate, High
- Combine Likelihood events in turn using a matrix to give single likelihood
- Determine consequence
- Use matrix to combine Likelihood and Consequence

**Risk estimation matrix**

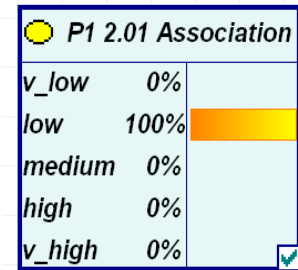
Likelihood of pest entry, establishment and spread	High	Negligible risk	Very low risk	Low risk	Moderate risk	High risk	Extreme risk
	Moderate	Negligible risk	Very low risk	Low risk	Moderate risk	High risk	Extreme risk
	Low	Negligible risk	Negligible risk	Very low risk	Low risk	Moderate risk	High risk
	Very low	Negligible risk	Negligible risk	Negligible risk	Very low risk	Low risk	Moderate risk
	Extremely low	Negligible risk	Negligible risk	Negligible risk	Negligible risk	Very low risk	Low risk
	Negligible	Negligible risk	Negligible risk	Negligible risk	Negligible risk	Negligible risk	Very low risk
		Negligible	Very low	Low	Moderate	High	Extreme
	Consequence						

# Bayesian Belief Networks (BBNs)

- BBNs are probabilistic models that represent variables and their relationships
  - Instead of forcing a single answer, BBNs allow assessors to distribute their belief across multiple categories
  - If unsure whether a pest is “likely” or “very likely” to establish, can assign probabilities to both categories
  - **BBN inputs:** expert judgments, data, literature (as conventional approaches)
  - BBN combines inputs to calculate probabilities of different outcomes
  - **BBN outputs:** probability distributions over risk categories
  - Requires development of model structure to define relationships between variables (conditional probability table)
  - Still subjective, but no more than other approaches using categories
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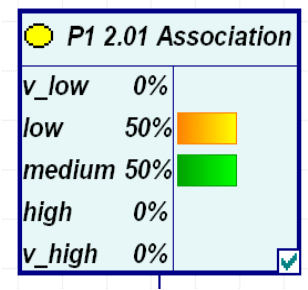
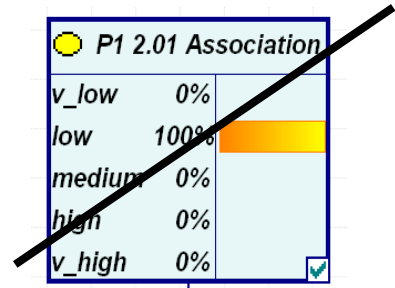
# BBN in practice

Entry Q1: Likelihood of association with the pathway at origin			
Rating	Description (likelihood of association is ...)	Justification summary	Probability Assignment <sup>1</sup>
Very Low	< 0.01% (less than one in ten thousand lots of the commodity are likely to be contaminated / infested)		-
Low	Between 0.01% and 0.1% (between one in ten thousand and one in one thousand lots are likely to be contaminated / infested)	<b>MacLeod (2018) states that 0.03% is infested</b>	<b>100%</b>
Medium	Between 0.1% and 1% (between one in one thousand and one in one hundred lots of the commodity are likely to be contaminated / infested)		
High	Between 1% and 10% (between one in one hundred and one in ten lots of the commodity are likely to be contaminated / infested)		-
Very High	> 10% (more than one in ten lots of the commodity are likely to be contaminated / infested)		
		Check sum =	100%



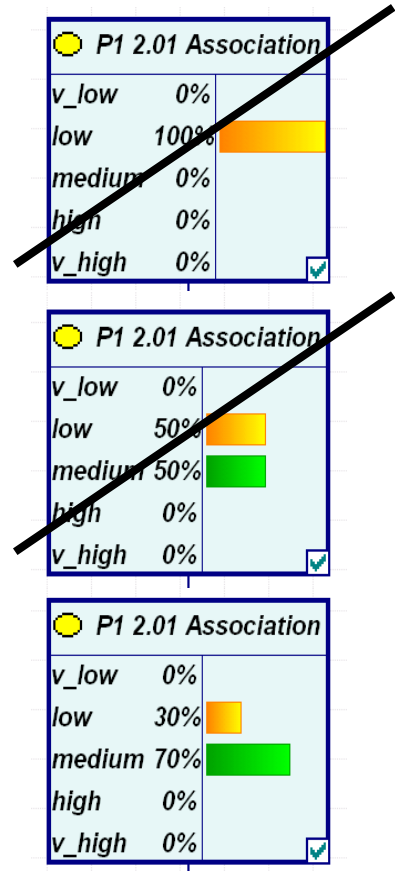
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<b>Very Low</b>	< 0.01% (less than one in ten thousand lots of the commodity are likely to be contaminated / infested)		-
<b>Low</b>	Between 0.01% and 0.1% (between one in ten thousand and one in one thousand lots are likely to be contaminated / infested)	<b>MacLeod (2018) states that 0.03% is infested</b>	<b>50%</b>
<b>Medium</b>	Between 0.1% and 1% (between one in one thousand and one in one hundred lots of the commodity are likely to be contaminated / infested)	<b>Kriticos et al. (2023) state that 0.6% is infested</b>	<b>50%</b>
<b>High</b>	Between 1% and 10% (between one in one hundred and one in ten lots of the commodity are likely to be contaminated / infested)		-
<b>Very High</b>	> 10% (more than one in ten lots of the commodity are likely to be contaminated / infested)		
Check sum =			100%



# BBN in practice

Entry Q1: Likelihood of association with the pathway at origin			
Rating	Description (likelihood of association is ...)	Justification summary	Probability Assignment <sup>1</sup>
Very Low	< 0.01% (less than one in ten thousand lots of the commodity are likely to be contaminated / infested)		-
Low	Between 0.01% and 0.1% (between one in ten thousand and one in one thousand lots are likely to be contaminated / infested)	<b>MacLeod (2018) states that 0.03% is infested</b>	<b>30%</b>
Medium	Between 0.1% and 1% (between one in one thousand and one in one hundred lots of the commodity are likely to be contaminated / infested)	<b>Kriticos et al. (2023) state that 0.6% is infested, much bigger study, better design</b>	<b>70%</b>
High	Between 1% and 10% (between one in one hundred and one in ten lots of the commodity are likely to be contaminated / infested)		-
Very High	> 10% (more than one in ten lots of the commodity are likely to be contaminated / infested)		
Check sum =			100%



# Bayesian Belief Network

- A Bayesian belief network is a probabilistic statistical graphical model representing variables and their dependencies in a directed network  
e.g. entry pathway model

2. Survives  
harvest

3. Survives  
storage &  
transport

4. Survives  
current  
measures

5. Volume  
imported

6. Chance  
of transfer

1. On  
pathway at  
origin

2a.  
Associated

3a.  
Travels

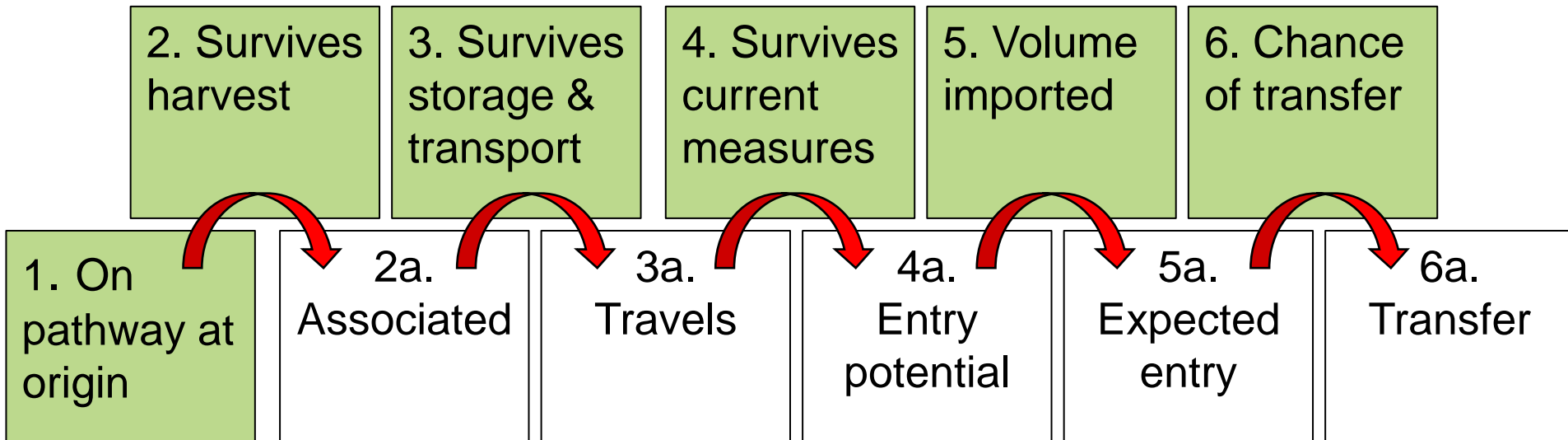
4a.  
Entry  
potential

5a.  
Expected  
entry

6a.  
Transfer

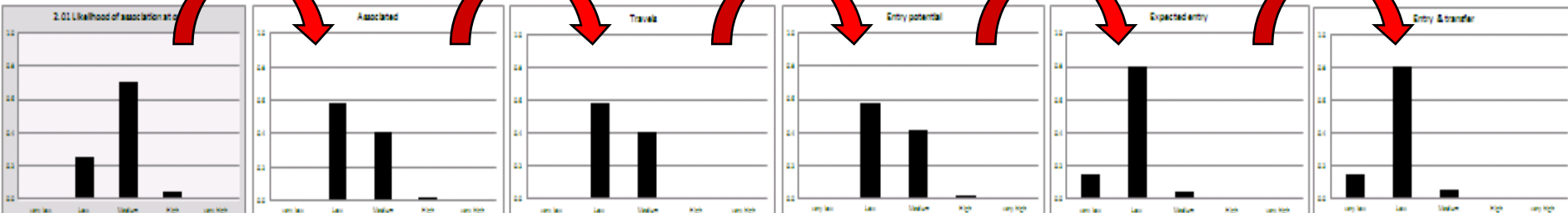
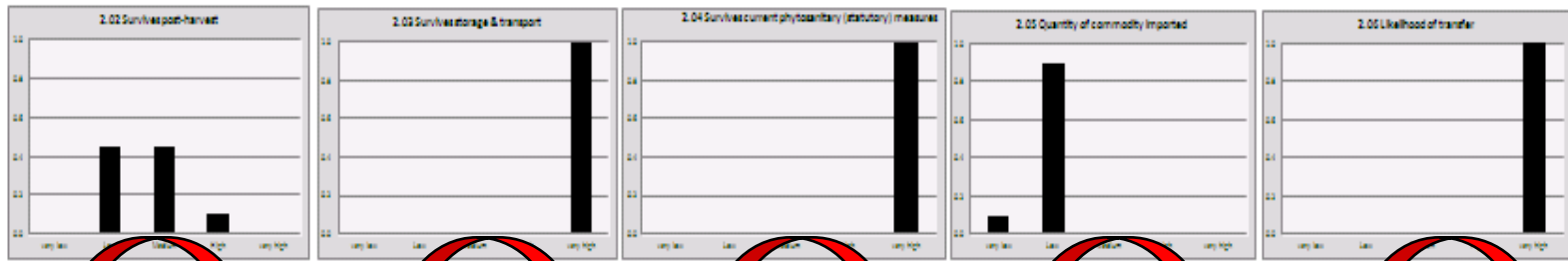
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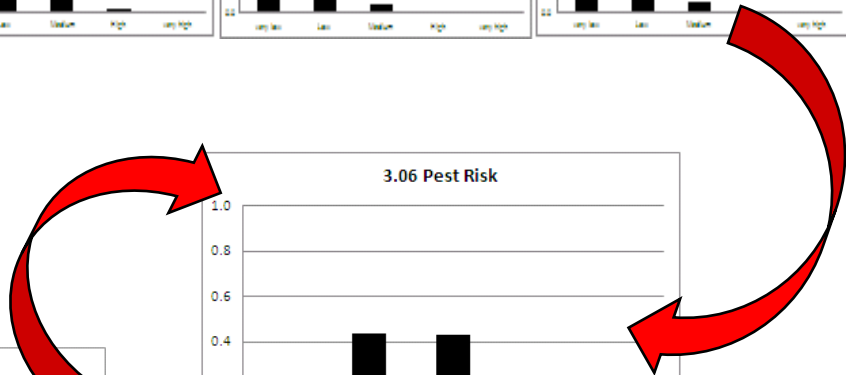
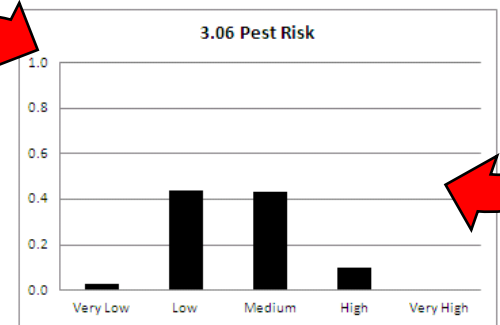
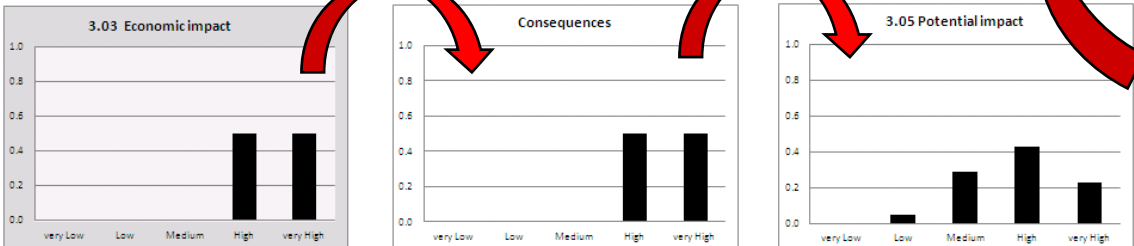
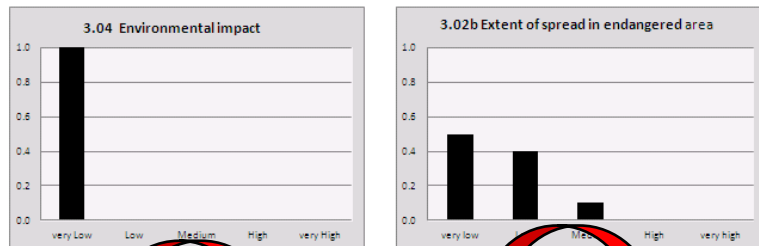
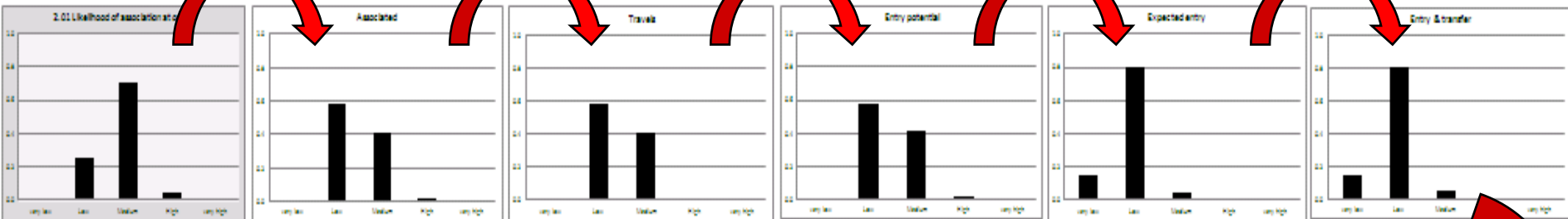
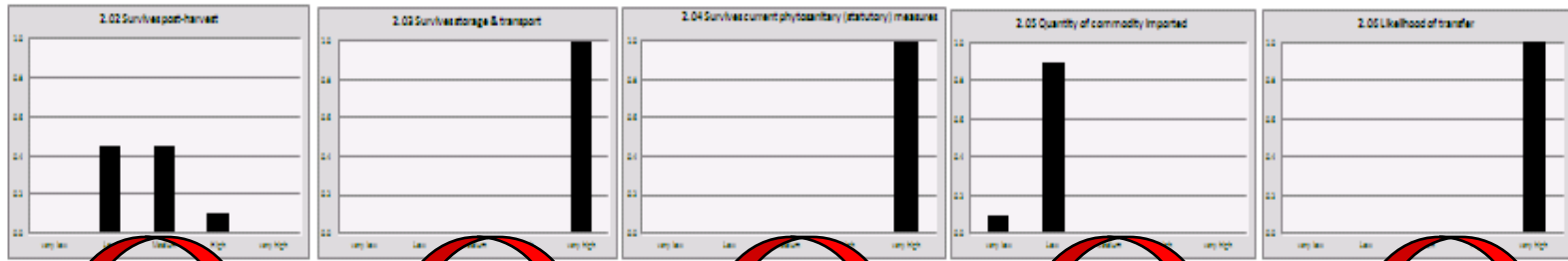


# Bayesian Belief Network

- Entry pathway model for *Xanthomonas citri* pv. *citri* (citrus canker)
- Originates in Asia, spread to Americas and Africa, consider import of ornamental rutaceous plants (e.g. *Murraya*) or plant parts
- Most uncertainty around start of pathway, once on pathway will survive but low quantities imported, no need to transfer



# BBN Model

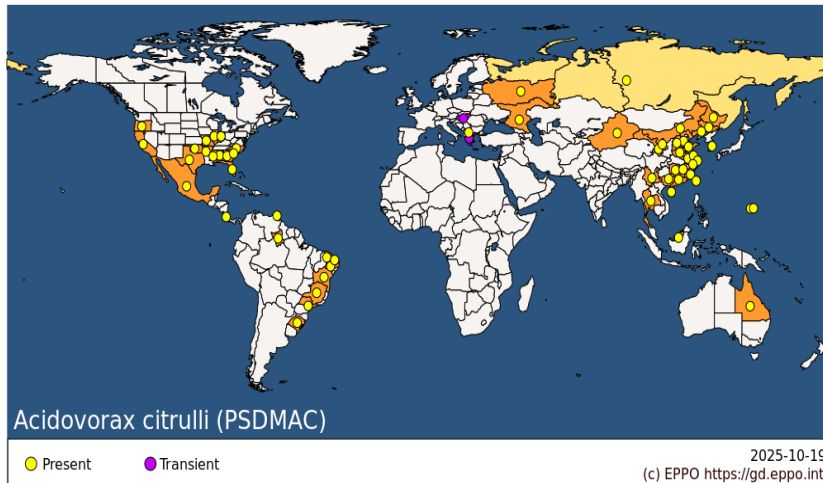


# Evaluating phytosanitary measures: case study *Acidovorax citrulli*

- Bacterial blotch of cucurbits (watermelons)
- Described in USA, 1965
- Pathways = seed, seedlings
- Spread internationally during 1990s with increased trade in cucurbit seed
- Not established in Europe
- Outbreaks in Greece, Hungary & Italy



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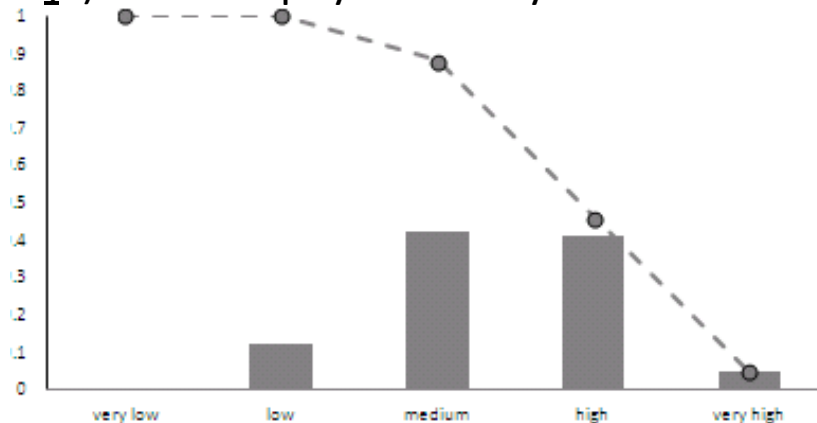


# Evaluating phytosanitary measures: case study *Acidovorax citrulli* - entry

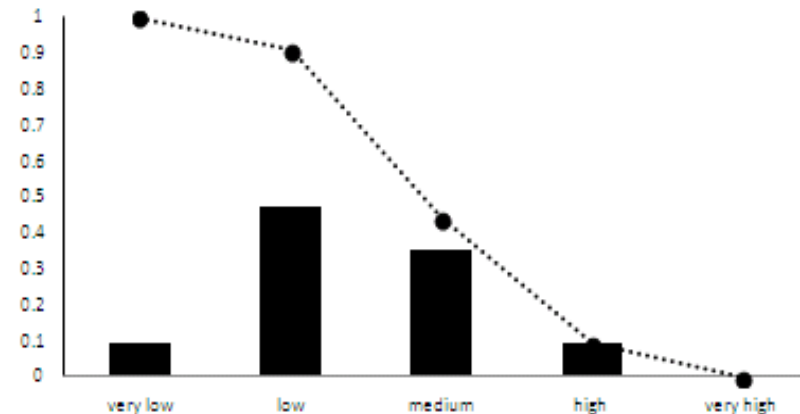
- Consider source countries, association at origin, survival, trade volume ...
- Assign beliefs (input judgements) into BBN to assess pathway without phytosanitary measures in place
- Identify measures (e.g. seed treatment; chemicals & testing not 100% effective)
- Repeat assessment assuming measures are in place

## Likelihood of entry into EU of *Acidovorax citrulli* via cucurbit seed

(a) Without phytosanitary measures

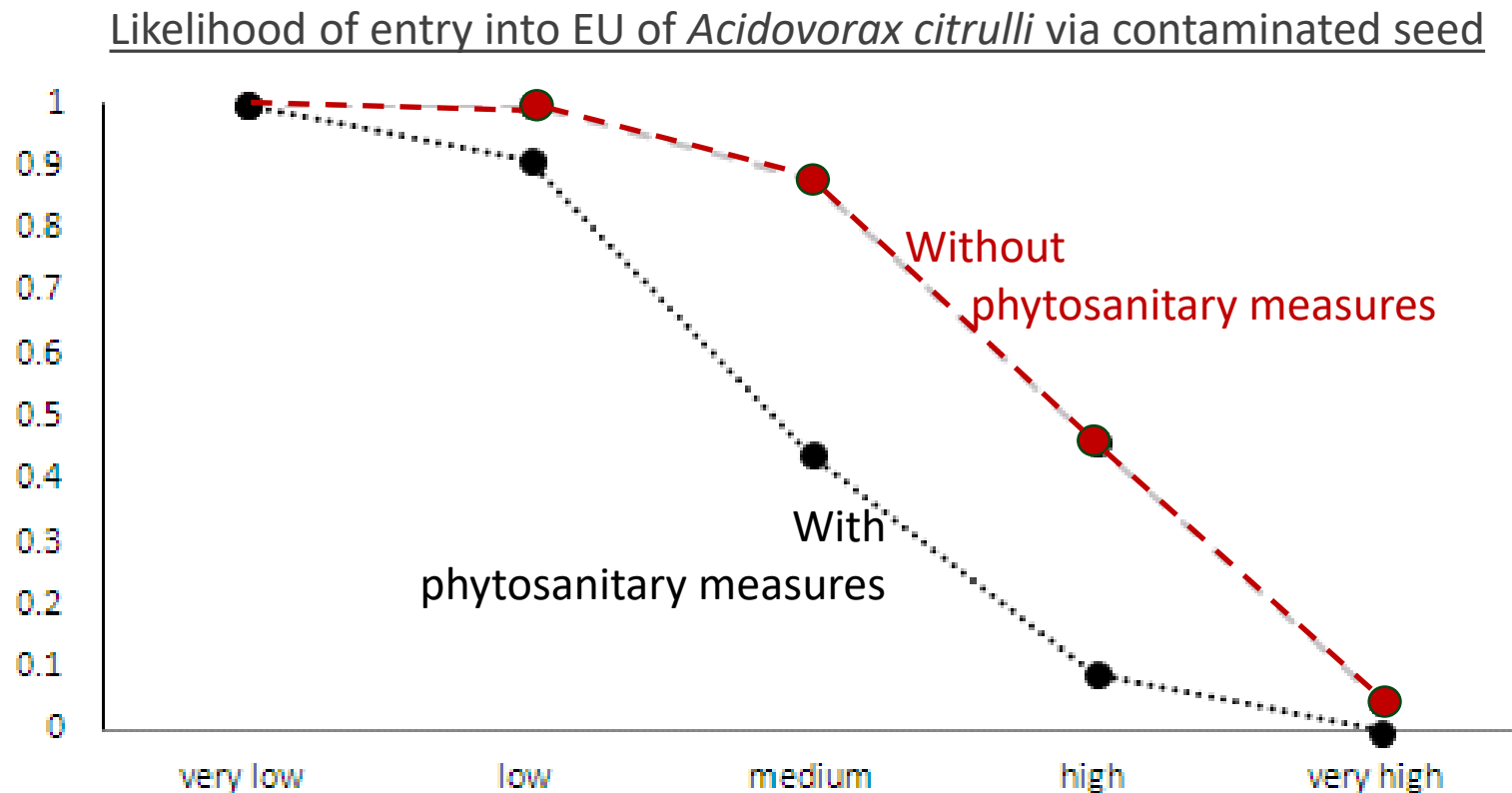


(b) with phytosanitary measures



# Evaluating phytosanitary measures: case study *Acidovorax citrulli* - entry

- Reducing area under curve, indicates lower risk
- If risk not reduced to acceptable level, consider stronger measures



# Conclusions

- BBN approaches offer a powerful way to enhance PRA by embracing uncertainty and improving transparency
  - Shows how each risk element contributes to the overall risk
  - Identifies where more data is needed to narrow uncertainty (research needs)
  - Evaluates phytosanitary measures / management measures
  - With increasing threats from plant pests, tools like BBNs can help make smarter, more informed decisions
-

Thank you



# BBN representation of a conventional risk matrix

Introduction		2.Establishment		
		Low	Medium	High
1.Entry	Low	Low	Low	Medium
	Medium	Low	Medium	High
	High	Medium	High	High

BBN: Conditional Probability Table

1.Entry	Low			Medium			High			
	Low	Medium	High	Low	Medium	High	Low	Medium	High	
2.Establishment	Low Risk	100%	100%	0%	100%	0%	0%	0%	0%	0%
Medium Risk	0%	0%	100%	0%	100%	0%	100%	0%	0%	0%
High Risk	0%	0%	0%	0%	0%	100%	0%	100%	100%	0%

